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Título del proyecto:

ANALYSIS OF EFFORTS ON A TUBULAR CHASSIS

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ABSTRACT

The objective of this project is to design a tubular chassis of a speed car, based on a earlier design of this type of car. When it is designed, the aim is to design it with a finite element program, in this case, is going to be used the software Abaqus, for after establish a method of calculation in a manner in which can be measured all the parameters, like deformations and stresses, suffered by the chassis submited to the efforts supported by the chassis in different situations, these are, the maximun acceleration, maximun decceleration, maximun cornering situation and crash situation.

At the same time, the aim of the project, is to get a chassis as light, strong and economical as possible, taking in account that the time avaiable for the design of it, is limited.

To perform this project, is essential to know the criteria used by tubular chassis designers in different competitions, like Formula Student, and also, the requirements demanded by the Royal Spanish Automobile Federation for compete in the Spanish mountain championship.

At the time of design the chassis, it is necesary to make firstly a rough design of the chassis, keeping in mind the methods of manufacture of a tubular structure to provide the worker of a easiest work as possible, when its construction, using also less tubes as possible to get the lightest chassis, and therefore, the cheapest one.

Nowadays, in the world of automobile competition, the teams spend big amounts of money to get the lightest and more strength car, not taking in account the money, but in this project, the solution would be get the lightest, most strength and cheapest chassis as possible, in a combination of all of them.

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1. INTRODUCTION/BACKGROUND

In the last few years, many people who are compiting in the world of motorsport, are trying to get better cars. At first, they tried to modify their cars, but the results were not as good as they want, because if the modify something in the car that were not alowed in the level they were compiting, they have to take part in the proto cathegory, and the car were not very competitive in this level.

For those people, who wants to change their car, and they did not want waste lot of money, one of the solutionf founded was to buy a speed car. This is not very expensive, comparing to other cars from highter cathegorys, and is very fast, because the relation power/ weigh is very high, around 2.5 kg/hp and the price is about 30.000 €, when a WRC cathegory has around 4.0 Kg/hp and a much higher price. Comparing the power/weigh relation to more common cars, the VW Golf GTI has a 6.06 Kg/hp, the Porche 911 GT2 RS, has a power/weigh relation of 2.2 Kg/hp and the most powerful street car, the Bugatty Veyron, has a power/weigh relation of 1.9 Kg/hp.

This type of cars started compiting in around the year 2001, when the team Bango Racing Cars, design the first single-seater asphalt car for the mountain championship, according to the rules of Group CM of France. This car, which was extremely light and equiped with a motorbike motor of 1000 c.c., demonstrated very high competitivity in all the participations in the mountain championship. Seeing the posibilities offered by the car, in the year 2002, the royal spanish automobile federation, created the cathegory of CM for this type of cars. Since this year, we can see more cars each year compiting in the CM mountain championship.

Apart of the mountain spanish CM championship, this type of cars can also participate in the CM open of Spain. In this case, the races are celebrated in circuits, and the requirements that the car must meet are the same as in the mountain CM championship.

Nowadays, the automobile competition teams, spend big amounts of money on the design and construction of the vehicles, to get a lighter, stronger and safer car, and they do not care about the money. The objective of this project is to establish a method of design tubular chassis of speed cars in a manner in wich can be change parameters of the strucuture of the tubular chassis to get lighter, stronger and cheaper to manufacture, in a combination of all of them.

The speed cars are made by cold drawn carbon steel tubes structure and glass fiber bodywork. It has got a motorbike engine, with 1000 c.c. and around 180 hp.

1.1. THE SPEED CAR

The speed car, is a car with tubular chassis, made by cold drawn charbon steel tubes, and glass fibre bodywork. It has four wheels in constant contact with the road. The rear wheels provide the car of the traction, and the front wheels provides the direction. The engine transmits movement to the differential self-locking of discs and ramps regulable by a chain. After, the differential transmits the movement to the wheels by the axles, to provide the traction to the car.

The speed car is agile, fast and powerful, due that it has 450 kg and motorbike motor with maximun 1000 c.c. and four cylinders and 180 hp.

The maximun measures of the speed car are the following:

a) Length: The maximum length of the vehicle may not exceed 3750 mm.

b) Width: The overall width of the vehicle may not exceed 1,750 mm.

c) Height: Height measured vertically from the lowest point of the flat surface to highest point vehicle must not exceed 1,030

2. AIMS OF THE PROJECT

The aim of this project is to design a tubular chassis of a speed car, using a method with which could optimize the characteristics of the chassis easily, changing different parameters into the software and submiting the chassis to a different efforts, like normal loads, the loads that the chassis suffer when it is cornering, accelerating or braking, and if the chassis support crash situations.

At the time to check if the chassis supports crash situations, the design goal is that the cockpit structure will not deformed at all. By contrast, the rest of the chassis, as the front and rear parts of the speed car, where are the direction and the engine, they must be weaker than the cockpit where the driver is situated. In this way, when the car suffer a crash, these two can deform, absorbing most of the energy of impact, resulting in the pilot, the least damage possible.

The loads that the car must support are the following:

- Static calculation

The car, must not have less than 445 kg, with the fuel tank empty and with the level of oil in good level. When the car is compiting, it must not have less than 550 kg, with the pilot. If the car does not have this weight, it will have wear ballast.

- Dinamic calculation

-Accelerating calculation: When boot a vehicle appears an inertial force that opposes the force that tends to set in motion the vehicle and modifying the loads on axles. When starting a vehicle the inertial force is higher on the rear axle than when the car is stationary. The opposite happens on the front axle, because the weight is transferred from the front axle to the rear axle.

The maximun acceleration registered in a speed car, accelerating from 0 Km/h to 100 Km/h, was measured in 5 seconds.

The acceleration is given by $a = \frac{v}{t}$, so, when the car accelerates from 0 Km/h to 100 Km/h (0 m/s to 27.77 m/s), the car suffer the next acceleration:

$$a = \frac{v}{t} = \frac{27.77}{5} = 5.55 m/s^2$$

Talking in G force units, this is 0.566 G.

-Braking calculation: When braking a vehicle appears an inertial force that opposes the force that tends to set to stop the vehicle and modifying the loads on axles. For braking, the inertial force is higher on the front axle than when the car is stationary. The opposite happens on the rear axle, because when the kart brake, the weight is transferred from the rear axle to the front axle.

The maximun braking registered in a speed car, braking from 100 Km/h to 0 Km/h, was measured in 2.3 seconds.

The braking deceleration is given by $a = \frac{v}{t}$, so, when the car accelerates from 100 Km/h to 0 Km/h (27.77 m/s to 0 m/s), the car suffer the next deceleration:

$$a = \frac{v}{t} = \frac{27.77}{2.3} = 12.07 m/s^2$$

Talking in G force units, this is 1.23 G.

-Cornering calculation: We assume that the vehicle in a circle of radius R with constant speed v. For an inertial observer, outside the vehicle, the forces acting on the car are:

• weight
• reaction of the road
• the friction force

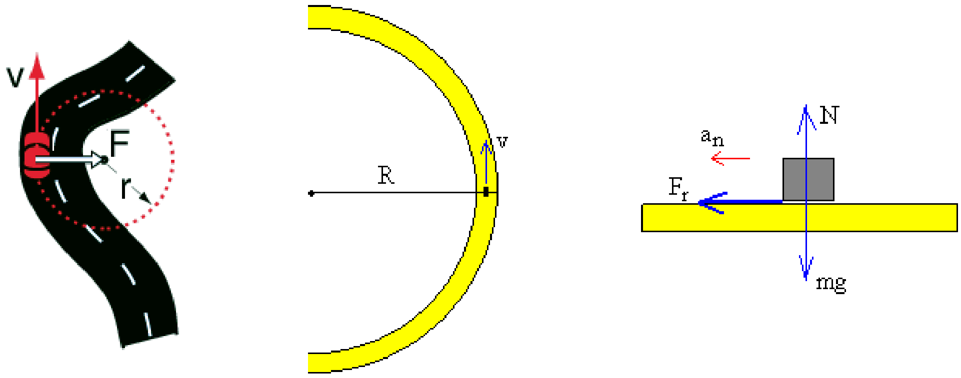


Figure 1: Load distribution of the car on curve

The last one, is what makes that the vehicle describe a circular travel.

As there is balance in the vertical plane reaction, equals the weight:

$$N = m \cdot G \qquad \text{Equation 1}$$

Applying Newton's second law of motion in the radial direction:

$$Fr = m \cdot a_n = m \cdot \frac{v^2}{R} \qquad \text{Equation 2}$$

Where v is the velocity of the moving and R is the radius of the circle that describes. As v increases the speed, increases the frictional force Fr until it reaches a maximum value given by the product of the coefficient of static friction by the reaction of the plane, μ N.

The maximum speed v that can reach the vehicle to describe a circular curve of radius R is therefore

$$m \cdot \frac{v^2}{R} = \mu \cdot N$$

$$v = \sqrt{\mu \cdot g \cdot R} \qquad \text{Equation 3}$$

If the velocity of the mobile increase, the friction force grows to a maximum value μ N, the vehicle's path is a circle.

If the mobile speed is higher than the maximum frictional force that is perpendicular to the velocity vector has a constant value and equal to its maximum value, the mobile trajectory ceases to be circular. To simplify the problem we have assumed that the coefficients of static and kinetic friction have the same value.

The maximum G force that can reach the vehicle when is cornering, we can know from the next mathematical development:

$$Fr = m \cdot a_n = \mu \cdot N$$

$$N = m \cdot G$$

$$m \, a_n = \mu \cdot m \cdot G$$

$$a_n = \mu \cdot G \qquad \text{Equation 4}$$

For our car, we know that the coeficient of friction for the tires is around 1.5, so, the maximun G force that the car should support, would be 1.5 G.

-Crash situation calculation: For the calculation of the crash situation, the rules of the mountain championship said that the chassis must support the following loads:

-2 times the weight of the car laterally.
-6 times the weight of the car longitudinally.
-8 times the weight of the car vertically.

-Minimun loads to support by the chassis: This loads are the weight of the engine, the weight of the pilot,

-Maximun deformations of the chassis: In the whole structure should not cause breakage or plastic deformation than the following values function of the instantaneous load:

- 50 mm, measured under load along the axis of load application.
- 100 mm, measured under load along the axis of load application.
- 50 mm, measured under load along the axis of load application.

- Torsion and flexion

For study how behaves the chassis in flexion and torsion, I am going to analyze it with the software Abaqus. For this, one end of the structure will be fixed, and on the other end will be applied a charge and a torque.

With this study it will be known which parts of the chassis suffers more.

After that, if the chassis does not support the loads applied, the distribution of the tubes will be modified, until find distribution of the tubes that resist the necesary loads.

3. ANALYSIS OF TASKS

The first thing to do, is define the most important points of the chassis. These are the suspension, wheelbase, pilot, direction and the mounting points of the harnes.

-Suspension: On the following figures, are defined the measures of the front and rear suspension.

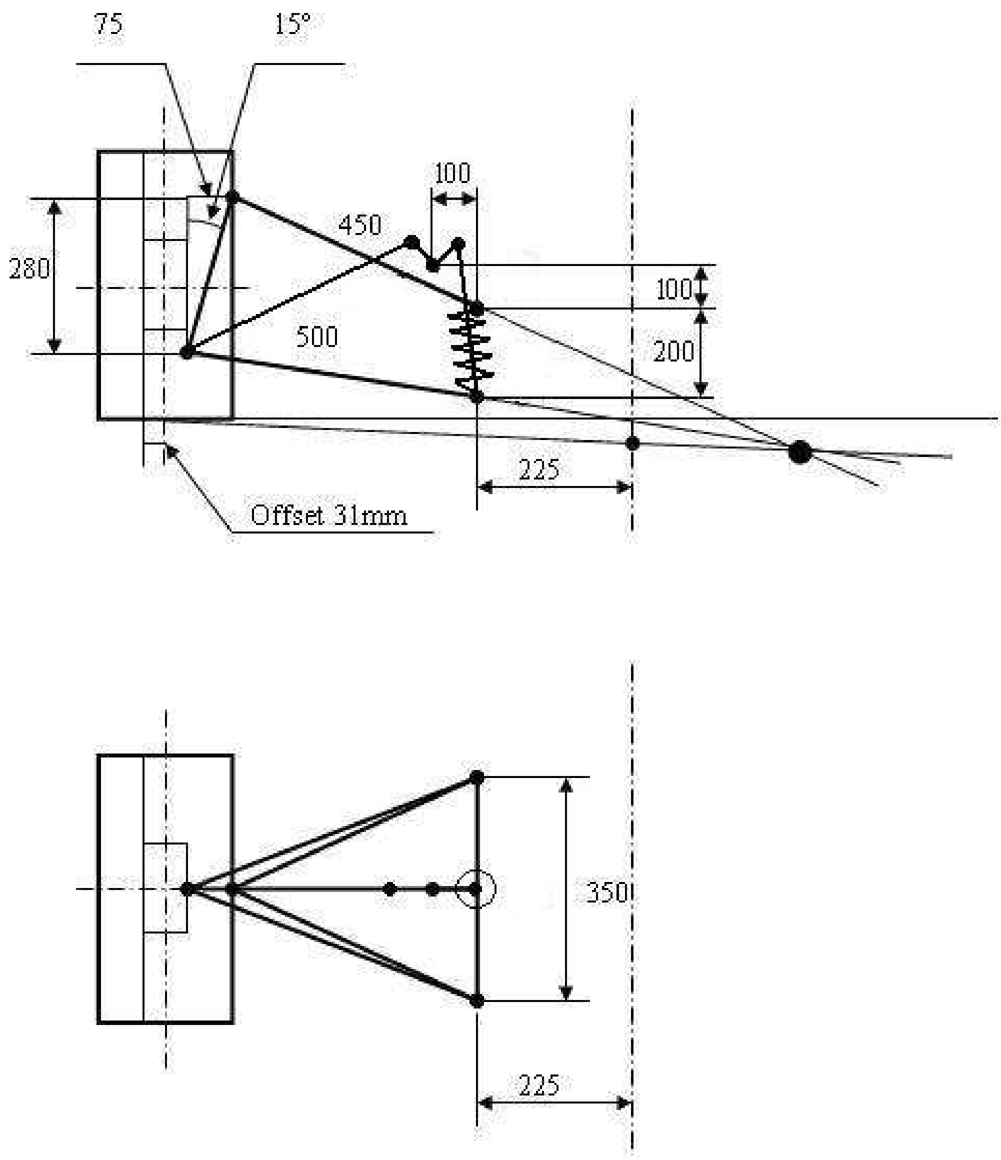


Figure 2: Detail of front suspension

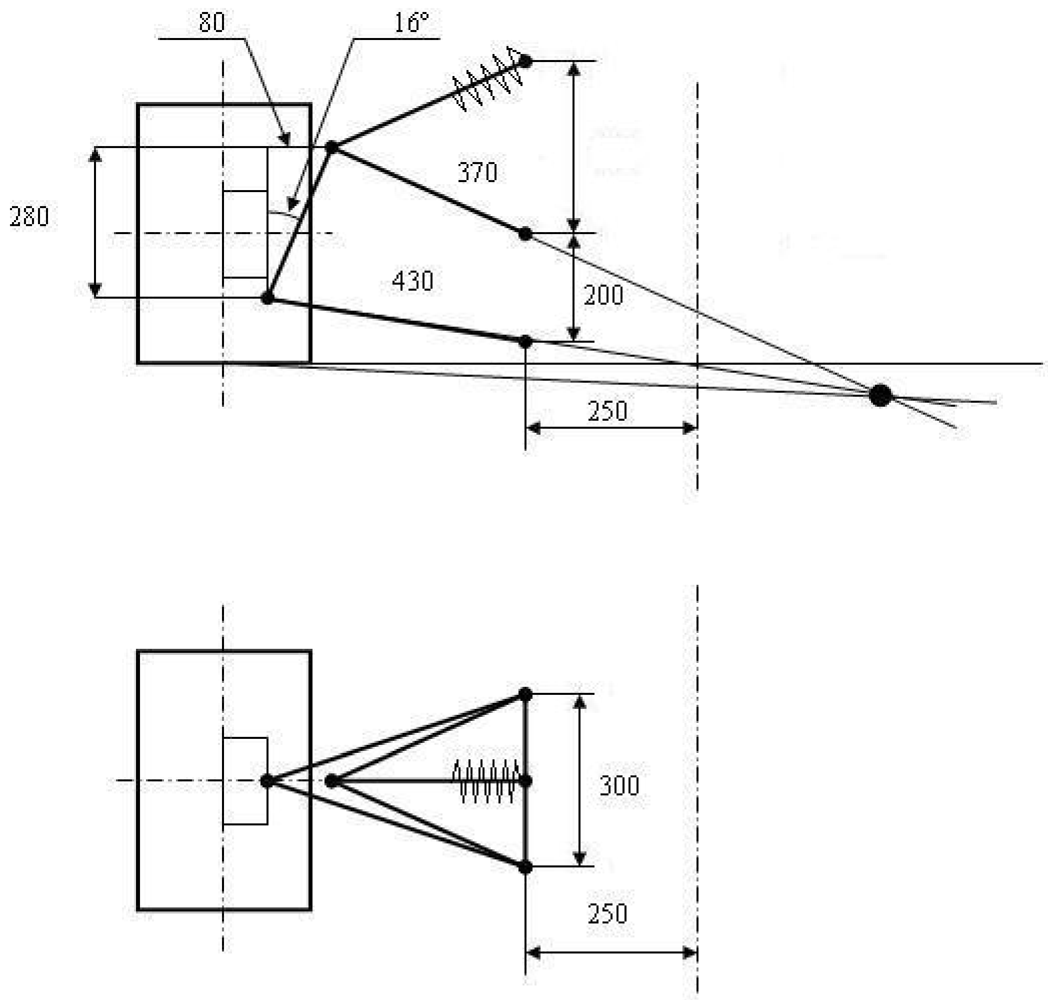


Figure 3: Detail of rear suspension

-Wheelbase: The distance between the front axle and the rear axle is 2800 mm.

-Pilot: The space for the pilot will be designed for males of 95th percentile with helmet.

The volume of the cockpit, should be symmetrical about the longitudinal axis of vehículo. To a height of 300 mm. from the floor of the vehicle, the driver must be located on one side of longitudinal axis, at the same being the normal driving position.

The minimum width at the elbows of the pilot, should be of 1,100 mm. maintained at a height of 100 mm and a length of 250 mm. This measure is taken horizontal and perpendiculary to the longitudinal axis of the vehicle.

The vehicle must have two legroom, defined as two symmetrical volumes to the longitudinal axis, which each must have a minimum volume of 750 cm2. The surface will be maintained from the plane of the pedals, to the vertical projection of steering wheel center.

The minimum width of the volume of foot position is 250 mm. maintained at a minimun height of 250 mm.

The plane positioning of the pedals should be such that the pilot's feet above them in stand does not exceed a vertical plane passing through the center of the front wheels.

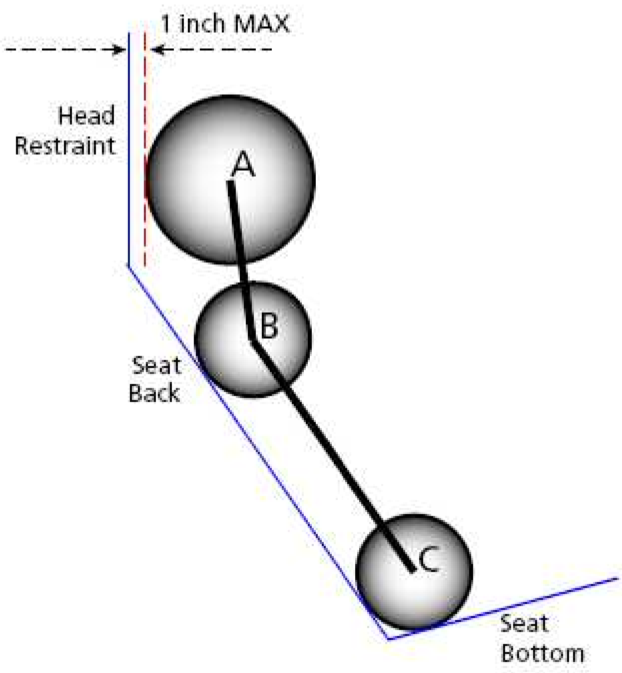


Figure 4: Position of the pilot

Circle A = Head with helmet – 300 mm diameter
Circle B = Shoulders – 200 mm diameter
Circle C = Hips and buttocks – 200 mm diameter

Line A-B = 280 mm from centerpoint to centerpoint
Line B-C = 490 mm from centerpoint to centerpoint

-Direction: For the direction, I have choosed the Anti-Ackerman geometry, because in the competition cars, where the lateral loads are very high, if we enter on curve with Ackerman geometry, the inside wheel rotate more degrees than the outer wheel, and in the middle of the curve, we find that the outer wheel, which rotates less degrees, stand the most loads, causing understeer on the the car. This is what happen in normal cars, when people enter in very high speed into the curve, the car skids on the front.

If we are using the Anti-Ackerman geometry, although it makes the car is more difficult to enter on the curve, at the time of maximum support the outer wheel is further rotated, so that we can create more drift angle and therefore more lateral grip. But if we exagerate this, we would obtain the opposite effect, and the car would going to oversteer, spinning the car from the rear axle.

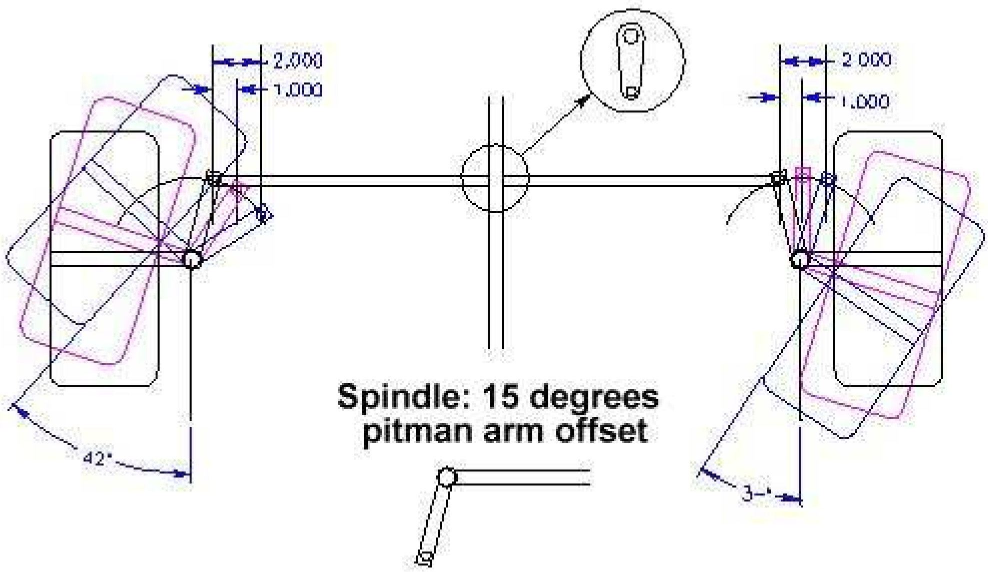


Figure 5: Detail of the direction

-Mounting points of harnes: It is prohibited for the seat belts to be anchored to the seats or their supports. A safety harness may be installed on the anchorage points of the series car.

The recommended geometrical locations of the anchorage points are shown in the next figures.

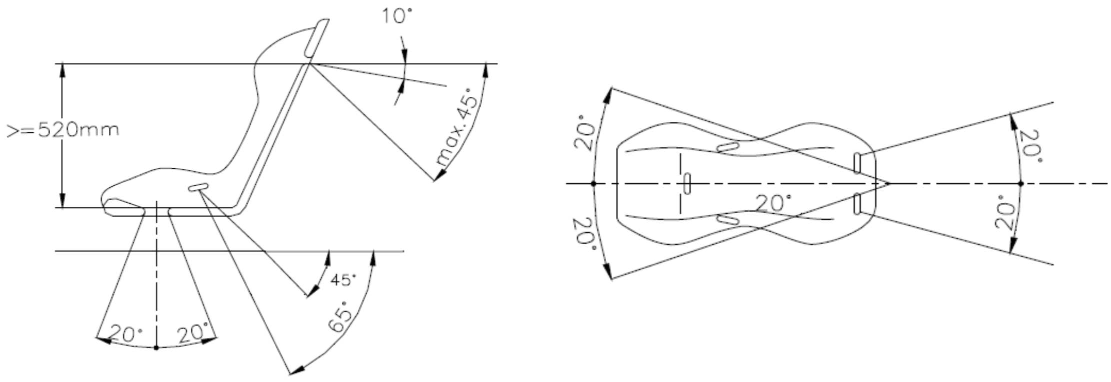


Figure 6: Recomended anchorage points

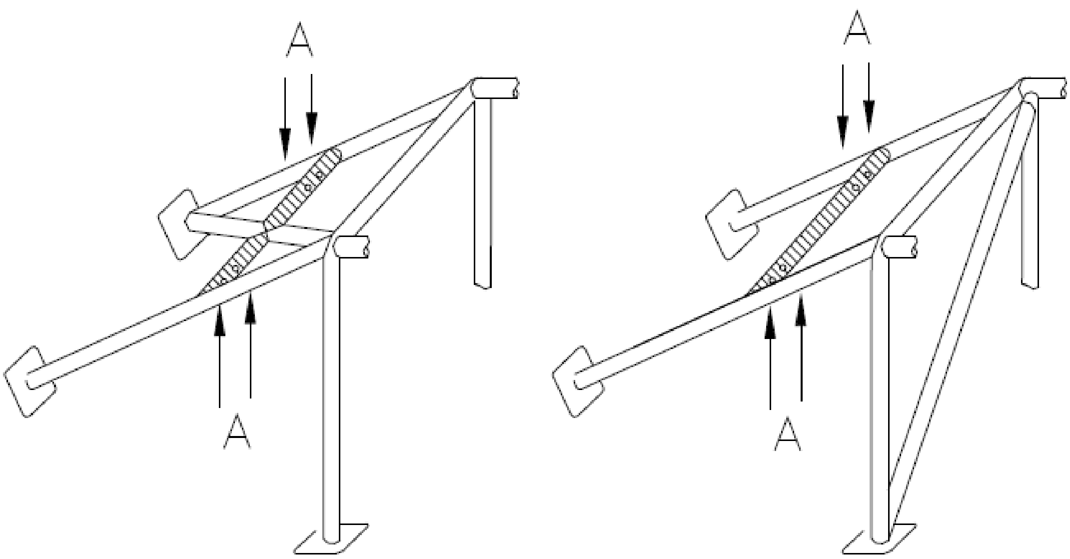


Figure 7: Recomended anchorage points

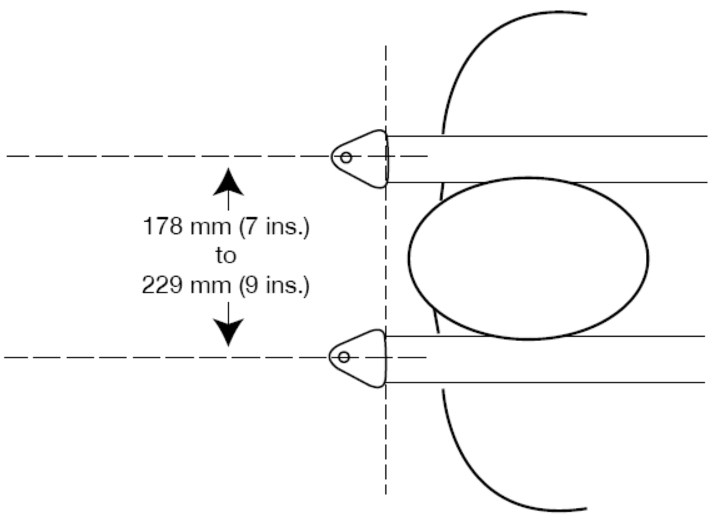


Figure 8: Distance of the anchorage points at shoulders

With all the important points of the car well defined, the next task to do, is start with the design of the chassis, joining all the important points defined before, with tubes. For this work, i must take care about have the less knots as possible for joining the tubes, because if I can reduce the number of the joining points of the bars, I am going to need less tubes, and this would mean, that the construction of the chassis will be cheaper.

It is found that the torsion stiffness is not much because the nodes must absorb much of the efforts in the form of bending moment. If you put a bar as shown in the figure below, the bar is working on axial stress (tension or compression) so that the node is suffering a smaller bending moment. Several studies show that the deformation due to axial stress is much lower, by orders of magnitude, due to bending moments and torsion. Therefore it is preferable that the bars are made to work to axial stress rather than bending moment or torque. This is achieved with triangulated structures. As for the type of axial stress, it is preferable traction to compression to avoid problems of buckling.

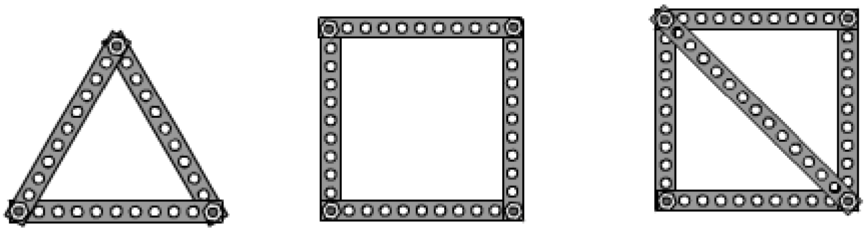


Figure 9: Distribution of tubes

In the design of a chassis, in terms of stiffness it must be taken into account the following points:

• There are elements that are not part of the structure but also provide rigidity, often not insignificant, for example, the engine. It must be taken into account when calculating.

• By decreasing the elastic modulus E because, for example, by choosing titanium or aluminum instead of steel, to not lower the overall stiffness the moment of inertia 'I' must be increased and also the area A must be increased by increasing the diameters of the tubes.

• The elements that produce high load such as motor and suspension should be tied into the chassis triangulated points.

• Driving controls should be set as best as possible so the chassis will not deform while driving.

• The bars with a higher distance between supports need a greatest moment of inertia for increase rigidity.

• The proper subjection of motor components is very important for a long life of the chassis.

• The seat belt brackets should not deform significantly during the crash.

• Although in a crash the bodywork should be deformed as much as possible, the part that protects the driver's feet should be rigid.

When all the parameters were defined, I am going to design the chassis, giving the form to the chassis, using steel tubes.

When I finish the design of the chassis, I am going to design it with the software Abaqus, for after analyze the efforts that suffer the tubes, submited to a differen loads, like when the car is cornering, accelerating, braking, and other type of situations when the chassis could be affected.

4. DESIGN OF A TUBULAR CHASSIS

One of the most important parts of the kart is the chassis. A chassis can be defined as a structure whose purpose is to rigidly connect the front suspension and rear grip and provide points for the various vehicle systems, as well as protect the driver against the collision. The chassis should be rigid to deform slightly and so does not alter the characteristics of driving. It is analogous to an animal’s skeleton. It is the most crucial element that gives strength and stability to the vehicle under different conditions.

Chassis is used mainly for cargo vehicles such as vans, trucks and buses, and also as reinforcement in the race cars such as Formula SAE / Student kartcross and NASCAR. It is known as a metal frame chassis, which are mounted on all components of the vehicle. The body is installed on the chassis once your application has been determined (in our case, kartcross). The installation proceeds bolting or welding the car body to the frame, if bolting is known as "coachwork independent" if welded known as self-supporting.

In competition vehicles it could be said that the two major types are monocoque and tubular frame.

In monocoque chassis the difference between the chassis and the body is diffuse, because the chassis is part of the bodywork.

Tubular chassis are the most commonly used as reinforcement of competition vehicles because their design is simpler and the determination of the stresses to which they can be subjected.

Regarding the mechanical behavior it must be said that the chassis is more rigid than the bodywork. It is interesting at the time of a crash, that the bodywork is deformed everything it can to not transmit the energy of the collision on passengers but the chassis should be deformed slightly so as not to alter the driving characteristics

The functions realized by the chassis are:

- It is the main support element of the vehicle: as it was said before, the chassis is analogous to an animal's skeleton; it is the element that supports all of the stress in the vehicle.
- It is the rigid connection between the rear axle and the front axle. In a vehicle, the distance between the front and the rear axle, should be constant.

- It gives to the kart the necessary rigidity for the possibilities that can occur when the forces are in motion.

- It protects the pilot against the collision. Is designed so that if an accident occurs, the frame will not break or deform very much and the pilot will have the less damage.

The chassis construction is the compromise between stiffness, weight and space, taking into account all the final cost. It should be considered static and fatigue resistance, stability of structural members, the load bearing capacity of the unions, manufacturing and assembly. In this project only take into account the efforts that may be considered static. For a complete measure of a chassis it should also be fatigue calculations and collision, which gives for a couple of other projects.

4.1. STIFFNESS CRITERIA

The overall expression of the stiffness is: $K = P / \Delta$

Where: P: applied load

Δ: deformation

The stiffness supplies the followings proportionalities: **K α ExI** and **K α ExA**

Where: E: modulus of elasticity or Young's modulus

I: moment of inertia

A: sectional area

Of these proportionalities follow that the higher modulus of elasticity, moment of inertia and / or sectional area, the greater the stiffness.

In the stiffness of a chassis, it takes into account two aspects: Bending stiffness and torsion rigidity.

Bending stiffness: Refers to how much the chassis bends due to the weight of the different elements of the vehicle. Experience tells us that it is not really a problem in the chassis design.

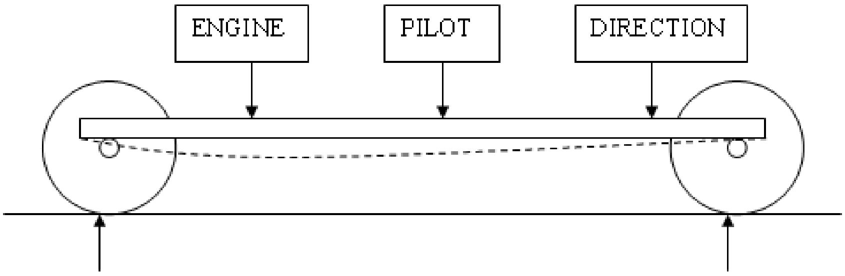


Figure 10: Loads that can bend the chassis

Torsion stiffness: This refers to how much a chassis deforms due to an asymmetric load, for example, when a front wheel goes over a bump while the other do not. This is the characteristic that should take care to validate in terms of chassis rigidity. According to the competition which is aimed to design the car is available for torsion rigidity or another. This depends on the maximum torque that can be subjected. This torque comes from the combined forces of the shock absorber. We should have to decide how many degrees we want it to be deformed when we applied the maximum torque, for example, one degree, an amount invisible to the human eye. Finally, the stiffness should be maximized to provide a safety margin and to obtain a round number. In a competition of Kartcross, a torsion rigidity of 150 kg • m/ ° is an acceptable amount. According to sources, in a race of Formula SAE/Student a reasonable torsion rigidity would be 500 kg • m/ °. According to other sources, for a NASCAR race would require 1500 kg • m/ ° of torsion rigidity.

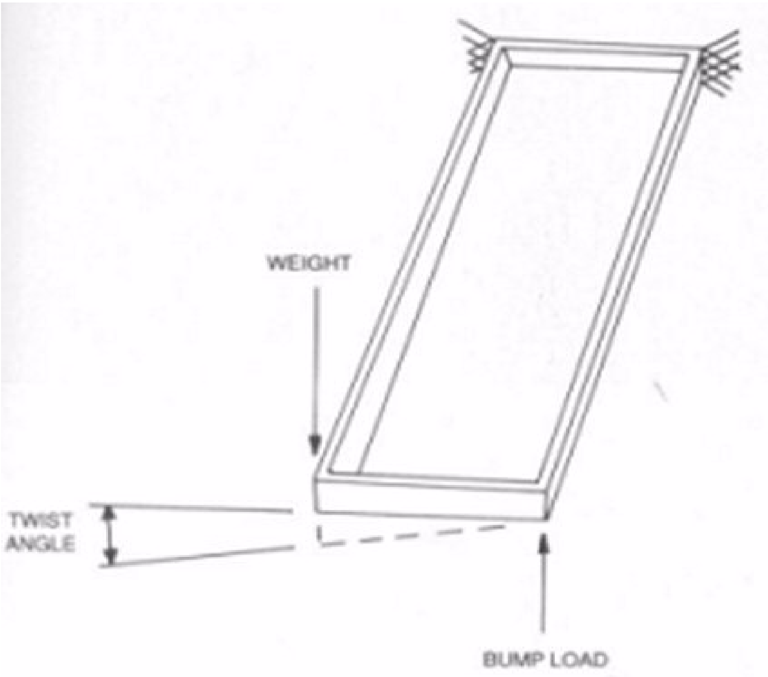


Figure 11: Frame torsion loads

Triangulation: For example, we have a rectangular structure to which a load is applied as is shown in the figure below.

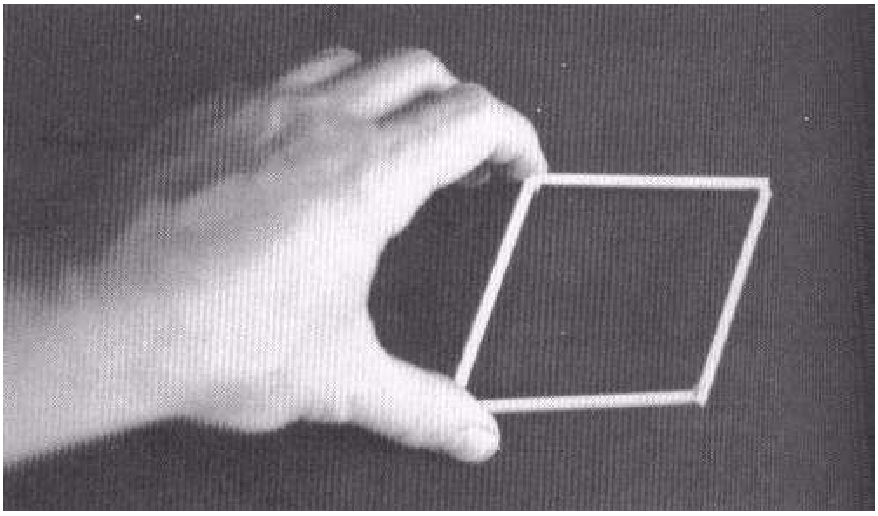


Figure12: Rectangular structure under torsión

It is found that the torsion stiffness is not much since the nodes must absorb much of the efforts in the form of bending moment. If you put a bar as shown in the figure below, the bar is working on axial stress (tension or compression) so that the node is suffering a smaller bending moment. Several studies show that the deformation due to axial stress is much lower, by orders of magnitude, due to bending moments and torsion. Therefore it is preferable that the bars are made to work to axial stress rather than bending moment or torque. This is achieved with triangulated structures. As for the type of axial stress, it is preferable traction to compression to avoid problems of buckling.

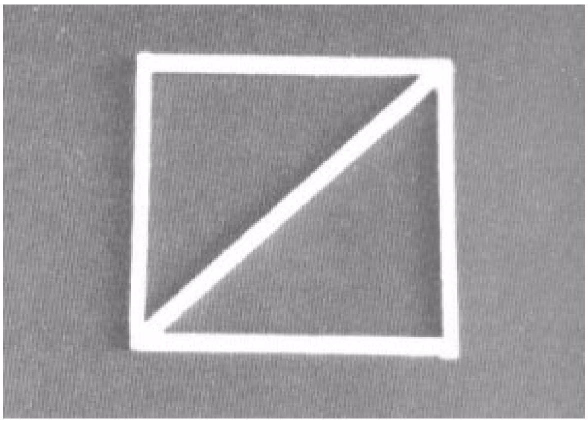


Figure 13: Triangulated structure

In the design of a chassis, in terms of stiffness it must be taken into account the following points:

• There are elements that are not part of the structure but also provide rigidity, often not insignificant, for example, the engine. It must be taken into account when calculating.

• By decreasing the elastic modulus E because, for example, by choosing titanium or aluminum instead of steel, to not lower the overall stiffness the moment of inertia 'I' must be increased and also the area A must be increased by increasing the diameters of the tubes.

• The elements that produce high load such as motor and suspension should be tied into the chassis triangulated points.

• Driving controls should be set as best as possible so the chassis will not deform while driving.

• The bars with a higher distance between supports need a greatest moment of inertia for increase rigidity.

• To increase the torsion stiffness could be added to the basic structure a side pod giving a greater moment of inertia. These side pods also increase the Lateral Impact Protection.

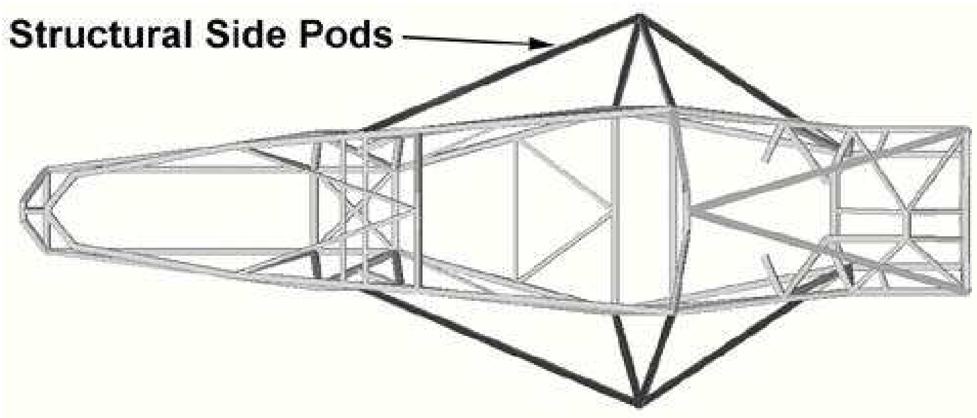


Figure 14: Structural side pods

• The proper subjection of motor components is very important for a long life of the chassis.

• The seat belt brackets should not deform significantly during the crash.

• Although in a crash the bodywork should be deformed as much as possible, the part that protects the driver's feet should be rigid.

4.2. CRITERIA ON THE WEIGHT AND ITS DISTRIBUTION

In the design of a chassis, in terms of weight and weight distribution must be considered the following points:

• The less the chassis weights, respecting the rigidity, the best engine power the kart will have.

• Regarding the studies done for the suspension, the center of gravity should be as low as possible to reduce rolling.

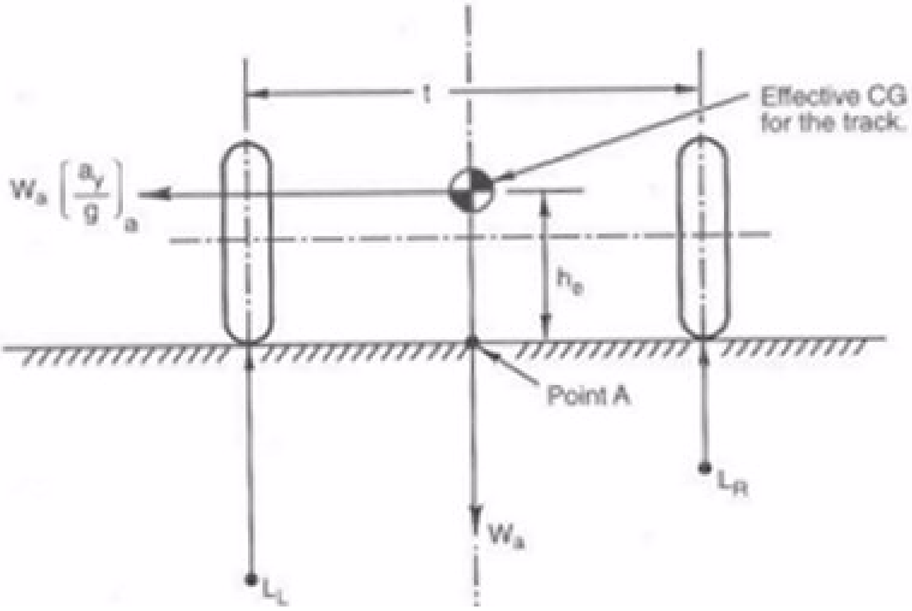


Figure 15: Weight distribution

• According to the aerodynamics studies, is known that the center of gravity should be the closest as possible of the center of lateral pressure to avoid driving instabilities due to sudden changes in a crosswind, for example, overtaking a truck. It is known that the center of lateral pressure is further back if the side surface is greater in the rear that up front.

In the figure shown below, is seen the pressure distribution because of the wind resistance on a car.

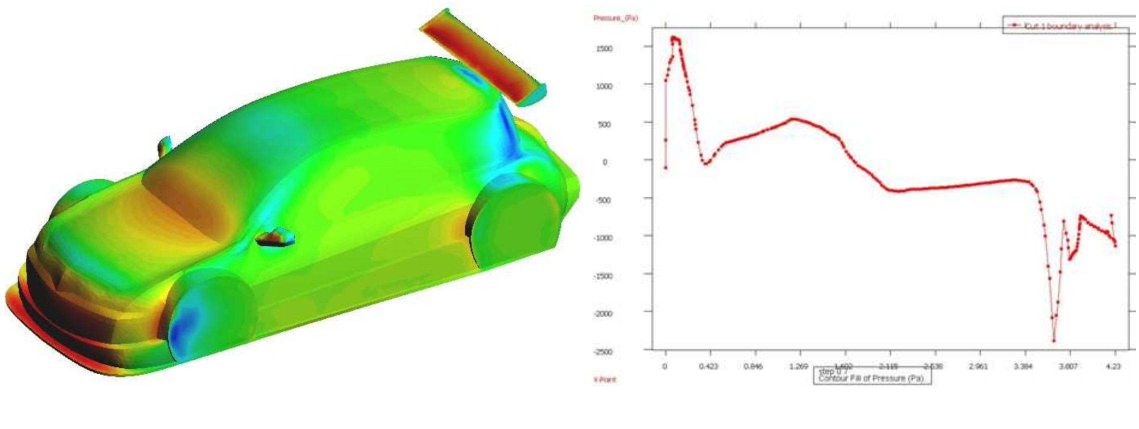


Figure 16: Resistance of the wind on a car

As is seen in the picture, the most resistance of the wind, is located in the front part of the vehicle. So that, to obtain more stability on the speed car, is needed more lateral surface in the rear part of the car, and also, the colocation of a spoiler, for increase the wind resistance in the rear part and displace the pressure centre to backward and locate closer to the centre of gravity of this.

4.3. SPACE CRITERIA

In the design of a chassis, in terms of space needs should take into account the following points:

• In the design of the structure, if there is transmission by chain, there should be enough space to mount a sprocket size range acceptable.

• It should be considered the ease of access for maintenance of propulsion elements.

• The 95 percentile man should be able to comfortably enter the car with the helmet. 95% percentile means that 95% of men are smaller than this model and that only 5% are bigger. The structure should not interfere with the driver in the movement for it to perform driving. A particular problem in this is the arms of driver.

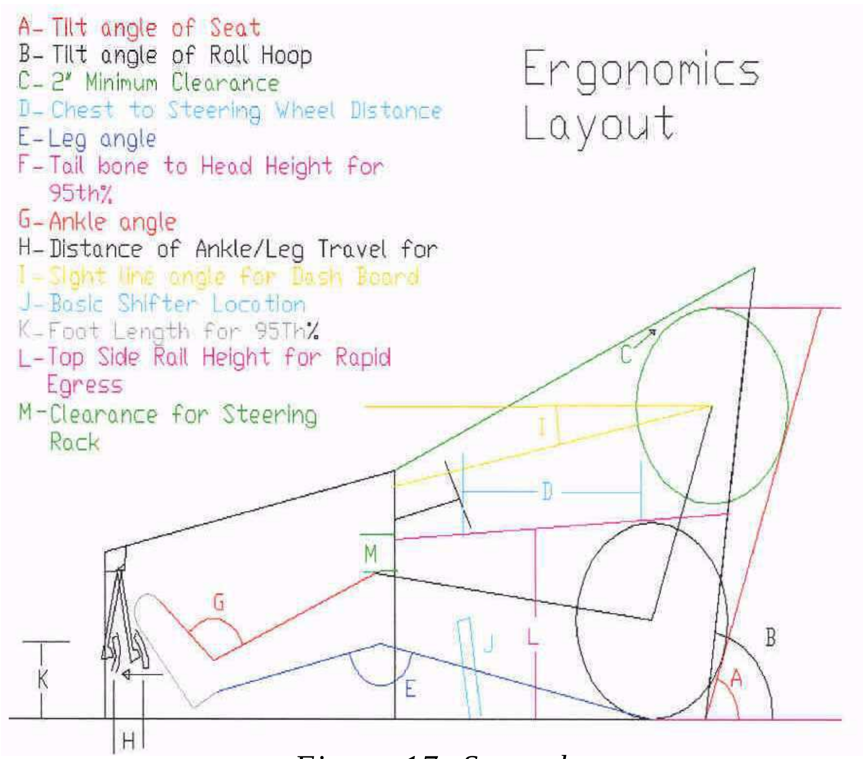


Figure 17: Space layout

• Measures of the pedals, the length and angle of the feet determine the height of the front of the chassis.
• The angle of the legs and body dimensions determine the length the seat.
• The sight line is used to determine the height of front rim.
• It is very important a rapid evacuation of the driver if there is an accident. For example, competition in Formula SAE / Student must be less than five seconds.

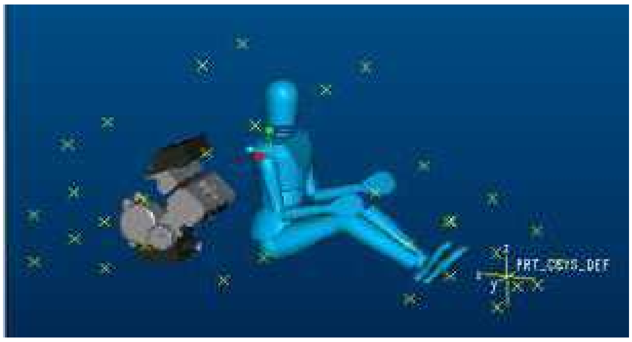


Figure 18: Situation of the driver and the engine

4.4. COST CRITERIA

In the design of a chassis, should be taken into account the following aspects to decrease the cost:

• The selection of bars should be the less varied possible in diameters.
• The number of bent bars should be as small as possible.
• The number of joints should be the minimum.
• In a welded construction of a tubular structure, almost all costs manufacturing bars correspond to the filling bars. It has been shown that with K-type joints could be obtained the minimum number of bars and filling joints. The spaced knots are easier to manufacture, because they simply apply a single cut on each end of the filling bar.
• The number of welds should be the minimum. This is achieved asking tubular profiles in extra long lengths.

4.5. APPLIED LOADS

The principal Efforts applied into a chassis are the bending and torsion. The bending is not as important as the torque because the bending does not affect the loads of the wheels, which are most affecting in the chassis. The car is also subject to stresses due to aerodynamics. The chassis must be formed that the air push the car down and the chassis should be rigid to deform. In a Kartcross tubular chassis type is not really important down force because the speeds are not large enough to have influence.

• The design efforts are the worst conditions:
 - Kart at maximum cornering speeds.
 - Hard acceleration.
 - Braking sharply in both, straight and curved.

• The points of application of the efforts include:
 - Brackets of the suspension (suspension forces).
 - Brackets where heavy loads are applied (and weight forces inertia).
 - The structure itself (weight and inertia forces)

The loads mentioned can be classified by their variation in time, as follows:

- Permanent loads G, for example, the weight of the structure, the weight of fixed equipment and driver.
- Varying loads Q, erg loads from the suspension or the inertia during acceleration, braking or cornering.

The variable loads are considered as quasi-static. It begins with the 'characteristic value' of the load, which is the average value of the load in a space of time. For example, is assumed that the kart is cornering. While it is cornering, the lateral acceleration will probably change as it will do the curve, because surely the driver will change the speed or the radius of curvature. This lateral acceleration produces an inertia loads that change in the same proportion as does the acceleration. It would be taken as the characteristic value of the load of inertia the average during the maneuver. It should be taken into a count the variability of the acceleration with time during the maneuver and not only the average arithmetic between the maximum and minimum value. Generally the characteristic value is called $\mathbf{F_k}$.

The characteristic value is multiplied by a partial safety coefficient $\boldsymbol{\gamma_k}$ adopted for the loading considered. This partial safety coefficient takes into account possible adverse deviation of the magnitude of the loads, an inaccurate modeling of the same or some uncertainty in the evaluation of the effects of the loads or limit state considered.

Thus, we have what is called 'load's calculus value':

$$\mathbf{F_d = \gamma_k \times F_k} \qquad \text{Equation 5}$$

In theory, there are two ways to determine the numerical values of partial coefficients:

1- For calibration of a long history and tradition constructive. This is the basic principle of most of the coefficients proposed in the current Eurocode.

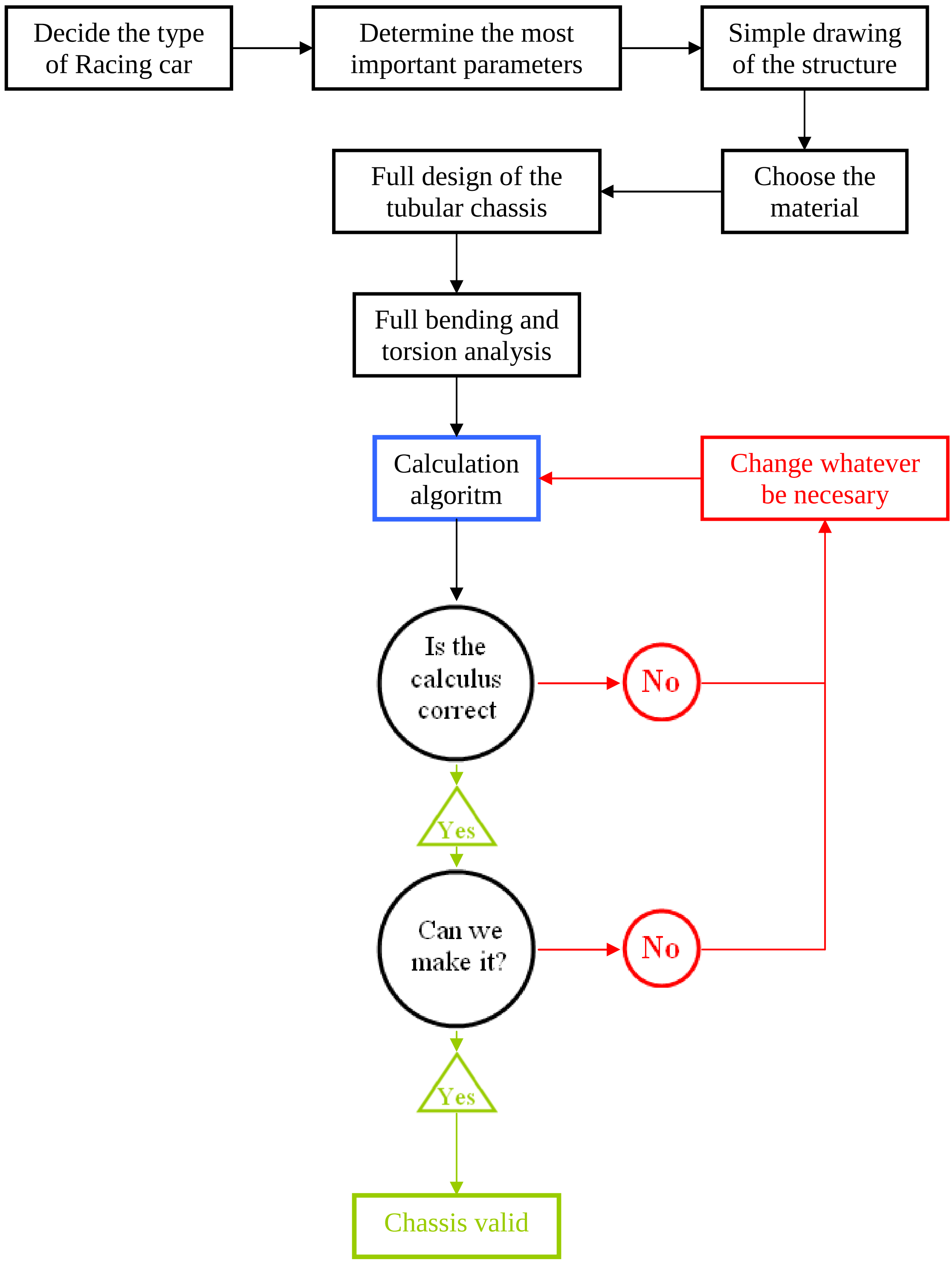
2- By the statistical evaluation of experimental data and field observations, and should be performed within the probabilistic theory of reliability.

Actually, to refine the calculated profiles, must be taken into account more factors, but usually, is taken the following values that are more conservative in order to simplify the calculation:

Permanent loads will have a coefficient $\boldsymbol{\gamma_G = 1.33}$

Variable loads will have coefficient $\boldsymbol{\gamma_Q = 1.15}$

5. DESIGN ALGORITM



6. TIMELINE

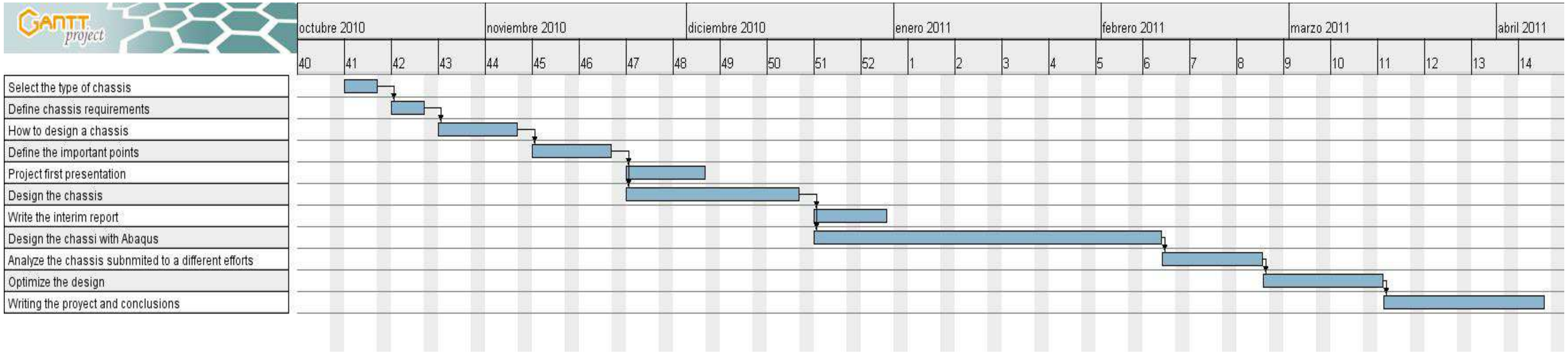


Figure 19: Project timeline

7. MATERIAL

The first question is, why steel? The chassis could also be made of titanium, aluminum or carbon fiber. The truth is that chassis can be made of almost any material but it must also be taken into account cost, mechanical behavior and formability possibilities it has.

The steel has the following advantages:

- Its price is relatively cheap
- Good weld ability
- Ductile material
- Its elasticity modulus is higher than many other materials such as titanium or aluminum. Thus the size of the section of the tube needed to have the same stiffness is lower.

As is mentioned in the introduction, the designer always needs to specify whether the material is cold-finished or warm-finished. The cold-finished tubular profiles are always welded, and the warm-finished tubular profiles, although most of them are also welded, may not have seam. In the case of the construction of a tubular chassis the most usual is to use cold-finished tubular profiles.

7.1. GENERAL PROPERTIES

Types 316 (UNS S31600), 316L (S31603), 317 (S31700) and 317L (S31703) are molybdenum-bearing austenitic stainless steels which are more resistant to general corrosion and pitting/ crevice corrosion than the conventional chromiumnickel austenitic stainless steels such as Type 304. These alloys also offer higher creep, stress-to-rupture and tensile strength at elevated temperature. Types 317 and 317L containing 3 to 4% molybdenum are preferred to Types 316 or 316L which contain 2 to 3% molybdenum in applications requiring enhanced pitting and general corrosion resistance. There is a 316LM alloy, a 2.5% minimum Mo version of Type 316L stainless steel, available only by special order.

Element	Percentage by weight (maximun Nules range is especified)			
	Type 316	Type 316L	Type 317	Type 317L
Carbon	0.08	0.030	0.08	0.030
Manganese	2.00	2.00	2.00	2.00
Silicon	0.75	0.75	0.75	0.75
Chromium	16.00-18.00	16.00-18.00	18.00-20.00	18.00-20.00
Nickel	10.00-14.00	10.00-14.00	11.00-15.00	11.00-15.00
Molybdenum	2.00-3.00	2.00-3.00	3.00-4.00	3.00-4.00
Phosphorous	0.045	0.045	0.045	0.045
Sulfur	0.030	0.030	0.030	0.030
Nitrogen	0.10	0.10	0.10	0.10
Iron	Bal.	Bal.	Bal.	Bal.

Table 1: Composition of materials

Types 316, 316L, 317 and 317L are more resistant to atmospheric and other mild types of corrosion than the 18-8 stainless steels. In general, media that do not corrode 18-8 stainless steels will not attack these molybdenum-containing grades. One known exception is highly oxidizing acids such as nitric acid to which the molybdenum-bearing stainless steels are less
resistant.

Generally, the Type 316 and 316L grades can be considered to perform equally well for a given environment. The same is true for Type 317 and 317L. A notable exception is in environments sufficiently corrosive to cause intergranular corrosion of welds and heat-affected zones on susceptible alloys. In such media, the Type 316L and 317L grades are preferred over Type 316 and 317, respectively, for the welded condition since low carbon levels enhance resistance to intergranular corrosion.

Physical properties: When properly annealed, Types 316 and 317 are primarily austenitic. Small quantities of ferrite may or may not be present. When slowly cooled or held in the temperature range 800-1500°F (427-816°C), carbides are precipitated and the structure consists of austenite plus carbides.
Melting Range: 2540-2630°F (1390-1440°C)

Density: 8.027 g/cm3

Modulus of Elasticity in Tension: 29 x 106 psi (200 Gpa)

Modulus of Shear: 11.9 x 106 psi (82 Gpa)

.

7.2. MECHANICAL PROPERTIES

Minimum mechanical properties for annealed Types 316, 316L, 317 and 317L austenitic stainless steel plate, sheet and strip as required by ASTM specifications A240 and ASME specification SA-240, are shown below.

Property	Minimum Mechanical Properties Required by ASTM A 240, and ASME SA-240			
	Type 316	Type 316L	Type 317	Type 317L
Yield Strength 0.2% Offset (Mpa)	205	170	205	205
Ultimate Tensile Strength (Mpa)	515	485	515	515
Percent Elongation in 51 mm	40.0	40.0	35.0	40.0
Hardness, Max. Brinell (R_B)	217	217	217	217

Table 2: Properties of materials

Effect of Cold Work Deformation of austenitic alloys at room or slightly elevated temperature produces an increase in strength accompanied by a decrease in elongation value. Representative room temperature properties of Types 316, 316L, 317 and 317L sheet in the annealed and cold worked conditions are shown in the following tables. Types 316, 316L, 317, and 317L flat rolled products are generally available in the annealed condition. Data for cold rolled strip are included as a guide to indicate the effects of cold deformation on properties during fabrication operations such as drawing and forming.

Percent Cold Reduction	Yield Strength 0.2% Offset	Ultimate tensile strength	Elongation Percent in 51 mm
Annealed	265	583	61.0
10	492	652	40.0
20	680	769	21.0
31	824	917	11.0
49	936	1,020	6.0
60	1,036	1,170	3.5

Table 3: Properties of type 316 according to the degree of annealing

Percent Cold Reduction	Yield Strength 0.2% Offset	Ultimate tensile strength	Elongation Percent in 51 mm
Annealed	299	612	54
10	535	702	38.3
20	696	839	22.8
31	822	994	15.3
49	1,000	1,203	7.8
60	1,144	1,341	5.8

Table 4: Properties of type 316L according to the degree of annealing

Percent Cold Reduction	Yield Strength 0.2% Offset	Ultimate tensile strength	Elongation Percent in 51 mm
Annealed	264	588	55.0
15	483	772	29.0
30	800	901	13.0
45	955	1,068	7.0
60	1,044	1,182	4.0

Table 5: Properties of type 317 according to the degree of annealing

Percent Cold Reduction	Yield Strength 0.2% Offset	Ultimate tensile strength	Elongation Percent in 51 mm
Annealed	336	614	48.0
15	684	775	23.3
30	822	979	15.3
45	967	1,159	9.3
60	1,026	1,269	7.5

Table 6: Properties of type 317L according to the degree of annealing

8. CALCULATIONS OF THE TUBULAR CHASSIS

8.1. LOAD DISTRIBUTION OF THE CHASSIS

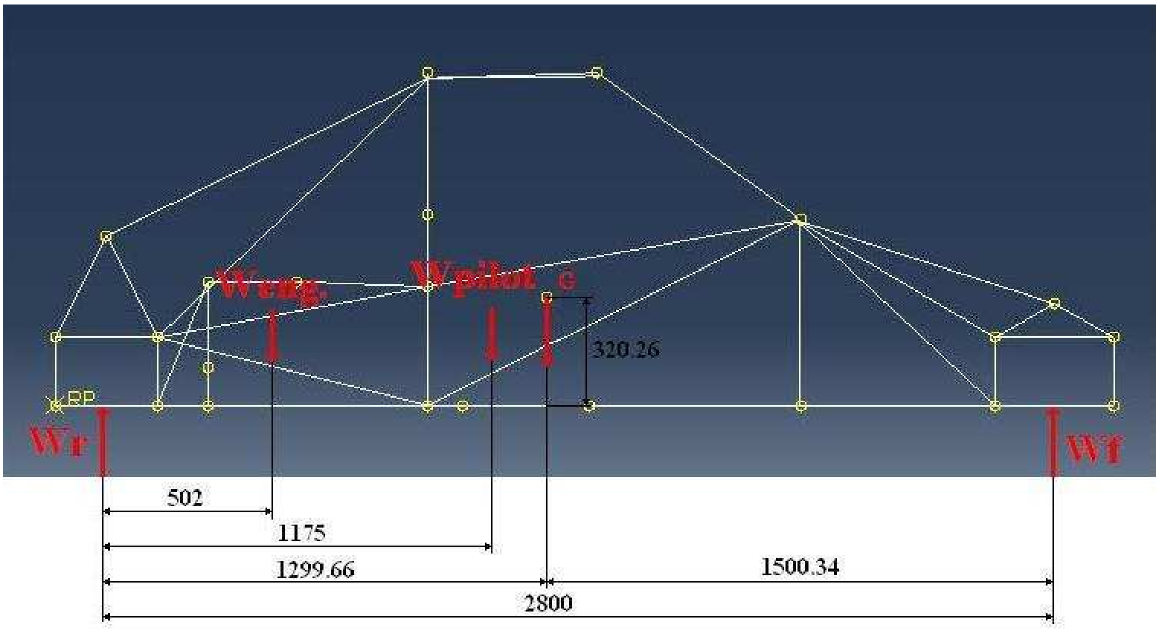


Figure 20: Load distribution of the chassis

Weng. = 105 Kg

Wpilot = 75 Kg

G = 340 Kg

$\Sigma F_y = 0 \qquad Wr - 105 - 75 - 340 + Wf = 0$

$$Wr = 520 - Wf$$

$\Sigma Mr = 0 \qquad 105 \cdot 502 + 75 \cdot 1175 + 340 \cdot 1299.66 - Wf \cdot 2800 = 0$

$$Wf = \frac{105 \cdot 502 + 75 \cdot 1175 + 340 \cdot 1299.66}{2800} = 208.1Kg$$

$$Wr = 520 - 208.1 = 311.9Kg$$

8.2. CALCULAIONS OF LOAD DISTRIBUTION

8.2.1. WHEN THE CAR SUPPORTS THE MAXIMUN ACCELERATION

-Inertia of the pilot on the seat´s brackets:

The inertia will be the force exerted by the pilot, it will be its mass multiplied by the maximun acceleration and it is applied on the four seat brackets as is shown below.

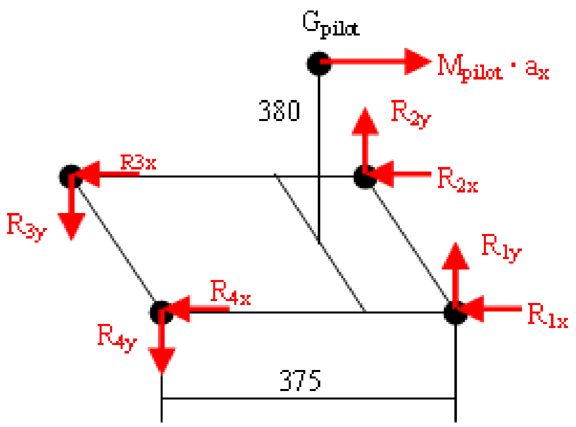


Figure 21: Inertia of the pilot in the acceleration

$M_{pilot} = 75$ Kg

$a_x = 0.566\ m/s^2$

Safety factor $\gamma = 1.33$

$R_{12x} = R_{1x} + R_{2x}$; $R_{1x} = R_{2x}$

$R_{34x} = R_{3x} + R_{4x}$; $R_{3x} = R_{4x}$

$R_{12y} = R_{1y} + R_{2y}$; $R_{1y} = R_{2y}$

$R_{34y} = R_{3y} + R_{4y}$; $R_{3y} = R_{4y}$

$\Sigma Fx = 0$ $\qquad M_{pilot}\, g \cdot a_x \cdot \gamma = R_{12x} + R_{34x}$

$$R_{12x} = R_{34x}$$

$$M_{pilot}\, g\, a_x\, \gamma = 2 \cdot R_{12x}$$

$$R_{12x} = \frac{M_{pilot}\, g\, a_x \cdot \gamma}{2} = \frac{75 \cdot 9.8 \cdot 0.566 \cdot 1.33}{2} = 276.6N$$

$$R_{1x} = R_{2x} = R_{3x} = R_{4x} = \frac{R_{12x}}{2} = 138.3N$$

$\Sigma M_{12} = 0$ $\quad M_{pilot}\, g\, a_x\, \gamma \cdot 380 = R_{34y} \cdot 375$

$$R_{12y} = R_{34y}$$

$$R_{34y} = \frac{M_{pilot}\, g\, a_x\, \gamma \cdot 380}{375} = \frac{75 \cdot 9.8 \cdot 0.566 \cdot 1.33 \cdot 380}{2} = 560.7N$$

$$R_{1y} = R_{2y} = R_{3y} = R_{4y} = \frac{R_{34y}}{2} = 280.35N$$

-Inertia of the engine on the engine brackets.

The mass of the engine is approximately 105 Kg and the contre of gravity has been placed like is shown below, with the reactions in the brackets.

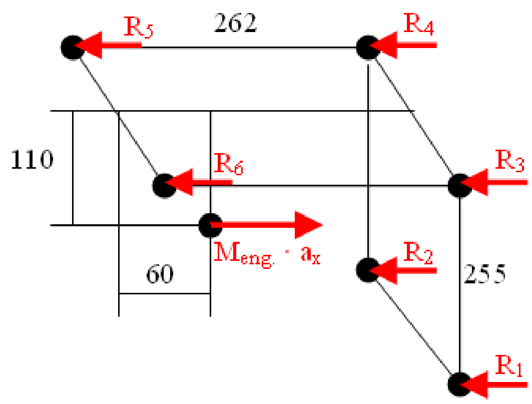


Figure 22: Inertia of the enginet in the acceleration

M_{engine}= 105 Kg

a_x = 0.566 m/s^2

Safety factor γ = 1.33

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

$\Sigma Fx = 0$ $\qquad R_{12} + R_{34} + R_{56} = M_{eng} \cdot g \cdot a_x \cdot \gamma$

$R_{34} = R_{56}$

$R_{12} + 2 \cdot R_{34} = M_{eng.} \cdot g \cdot a_x \cdot \gamma \quad (1)$

$\Sigma M_G = 0$ $\qquad R_{56} \cdot 110 + R_{34} \cdot 110 = R_{12} \cdot 145$

$2 \cdot R_{34} \cdot 110 = R_{12} \cdot 145$

$R_{34} = 0.66 \cdot R_{12} \quad (2)$

Substituing (2) into (1):

$R_{12} + 2 \cdot 0.66 \cdot R_{12} = M_{eng.} \cdot g \cdot a_x \cdot \gamma$

$2.32 \cdot R_{12} = M_{eng.} \cdot g \cdot a_x \cdot \gamma$

$$R_{12} = \frac{M_{eng.} \cdot g \cdot a_x \cdot \gamma}{2.32} = \frac{105 \cdot 9.8 \cdot 0.566 \cdot 1.33}{2.32} = 333.88N$$

$R_{34} = 0.66 \cdot 333.88 = 220.36$ N

$$R_1 = R_2 = \frac{R_{12}}{2} = \frac{333.88}{2} = 166.94N$$

$$R_1 = R_2 = R_3 = R_4 = \frac{R_{34}}{2} = \frac{220.36}{2} = 110.18N$$

-Inertia of the chassis itself.

The density of steel is ρ = 8000 Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value:

$$q = \rho \cdot A \cdot d \cdot \gamma \cdot g$$

Where:

q = Density of the steel = 8000 Kg/m^3

A = Area of tube section (m^2)

a = Acceleration of the car (m/s^2)

γ = Safety factor = 1.33

g = Acceleration of the gravity = 9.8 m/s^2

$$q_{\phi 50} = 8000\left((0.05^2 - 0.036^2)\cdot\frac{\pi}{4}\right)\cdot 0.566\cdot 1.33\cdot 9.8 = 55.8 N/m$$

$$q_{\phi 30} = 8000\left((0.03^2 - 0.027^2)\cdot\frac{\pi}{4}\right)\cdot 0.566\cdot 1.33\cdot 9.8 = 10.09 N/m$$

The direction of the force is the same than the speed car advance and with the opposite direction of acceleration of the vehicle as it is a reaction to progress.

-Weight of the pilot.

In the 95% of the casses, the mass of the pilot is taken M = 75 Kg, and in this case also it will be taken of 75 Kg. Therefore, the weight of the pilot will be M·g and it will applied in the four brackets that the seat is supported. It is shown below.

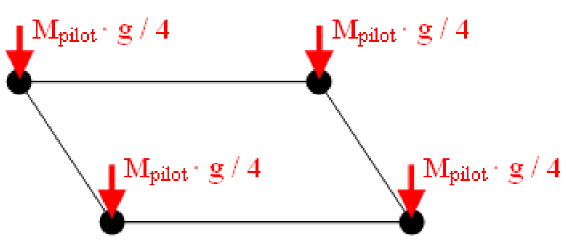


Figure 23: Weight of the pilot

$$F = \frac{M_{pilot} \cdot g}{4} = \frac{75 \cdot 9.8}{4} = 183.75 N$$

-Weight of the engine.

Using the equations of statistics:

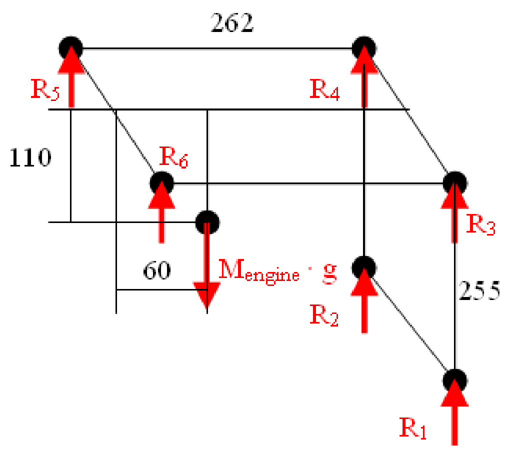


Figure 24: Weight of the engine

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

$\Sigma Fx = 0$ $\quad R_{12} + R_{34} + R_{56} = M_{eng} \cdot g \cdot \gamma$

$R_{12} = R_{34}$

$2 \cdot R_{12} + R_{34} = M_{eng.} \cdot g \cdot \gamma$ (1)

$\Sigma M_G = 0$ $\quad R_{56} \cdot 60 = R_{12} \cdot 202 + R_{34} \cdot 202$

$R_{56} \cdot 60 = 2 \cdot R_{12} \cdot 202$

$R_{56} = 6.73 \cdot R_{12}$ (2)

Substituing (2) into (1):

$2 \cdot R_{12} + 6.73 \cdot R_{12} = M_{eng.} \cdot g \cdot \gamma$

$8.73 \cdot R_{12} = M_{eng.} \cdot g \cdot \gamma$

$$R_{12} = \frac{M_{eng.} \cdot g \cdot \gamma}{8.73} = \frac{105 \cdot 9.8 \cdot 1.33}{8.73} = 156.77N$$

$R_{56} = 6.73 \cdot 156.77 = 1055$ N

$$R_1 = R_2 = R_3 = R_4 = \frac{R_{12}}{2} = \frac{156.77}{2} = 78.38N$$

$$R_5 = R_6 = \frac{R_{56}}{2} = \frac{1055}{2} = 527.5N$$

-Weight of the chassis itself.

The density of steel is 8000 Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value.

$$q_{\phi 50} = 8000 \cdot \left((0.05^2 - 0.036^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 98.6N/m$$

$$q_{\phi 30} = 8000 \cdot \left((0.03^2 - 0.027^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 17.82N/m$$

-Load transfer

$$Wf' = Wf - \frac{h_G}{L} \cdot \frac{W}{g} \cdot A_x \cdot g = 208.1 \cdot 9.8 - \frac{320.26}{2800} \cdot \frac{520}{9.8} \cdot 0.566 \cdot 9.8 = 2005.7N$$

$$Wr' = Wr + \frac{h_G}{L} \cdot \frac{W}{g} \cdot A_x \cdot g = 311.9 \cdot 9.8 + \frac{320.26}{2800} \cdot \frac{520}{9.8} \cdot 0.566 \cdot 9.8 = 3090.3N$$

8.2.2. WHEN THE CAR SUPPORTS THE MAXIMUN DECCELERATION

-Inertia of the pilot on the seat belt brackets:

When braking, the driver lifts off the seat and is restrained by the seat belt. The load sharing between the different brackets of the belt is complex to determine, so it will be assumed that is equal for all.

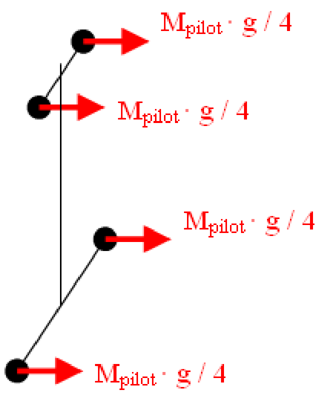


Figure 25: Inertia of the pilot in the braking

$$F = \frac{M_{pilot}\, d \cdot g \cdot \gamma}{4} = \frac{75 \cdot 9.81 \cdot 1.23 \cdot 1.33}{4} = 300.6N$$

As it was said before, the 95% of the cases, it is chosen as the mass of the pilot a value of 75 Kg, therefore, in this case, the mass will be 75 Kg. The value of the decceleration is 1.23 m/s^2 and the safety factor γ = 1.33.

-Inertia of the engine on the engine brackets.

The mass of the engine is approximately 105 Kg and the contre of gravity has been placed like is shown below. Taking a similar load balance than in the hipothessis of maximun acceleration, in this case we have the following reactions.

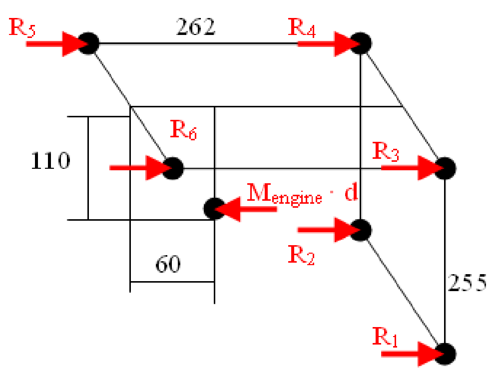


Figure 26: Inertia of the engine in the braking

M_{engine}= 105 Kg

d = 1.23 m/s^2

Safety factor γ = 1.33

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

ΣFx = 0 $\quad R_{12} + R_{34} + R_{56} = M_{eng}\cdot g\cdot d\cdot \gamma$

$R_{34} = R_{56}$

$R_{12} + 2\cdot R_{34} = M_{eng.}\cdot g\cdot d\cdot \gamma$ (1)

$\Sigma M_G = 0$ $\quad R_{56}\cdot 110 + R_{34}\cdot 110 = R_{12}\cdot 145$

$2\cdot R_{34}\cdot 110 = R_{12}\cdot 145$

$R_{34} = 0.66\cdot R_{12}$ (2)

Substituing (2) into (1):

$R_{12} + 2\cdot 0.66\cdot R_{12} = M_{eng.}\cdot g\cdot d\cdot \gamma$

$2.32\cdot R_{12} = M_{eng.}\cdot g\cdot d\cdot \gamma$

$$R_{12} = \frac{M_{eng.}\cdot g\cdot a_x\cdot \gamma}{2.32} = \frac{105\cdot 9.81\cdot 1.23\cdot 1.33}{2.32} = 725.6N$$

$R_{34} = 0.66 \cdot 725.6 = 478.9$ N

$$R_1 = R_2 = \frac{R_{12}}{2} = \frac{725.6}{2} = 362.8N$$

$$R_1 = R_2 = R_3 = R_4 = \frac{R_{34}}{2} = \frac{478.9}{2} = 239.45N$$

-Inertia of the chassis itself.

The density of steel is ρ = 8000 Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value:

$$q = \rho \cdot A \cdot d \cdot \gamma \cdot g$$

Where:

q = Density of the steel = 8000 Kg/m^3

A = Area of tube section (m^2)

a = Acceleration of the car (m/s^2)

γ = Safety factor = 1.33

g = Acceleration of the gravity = 9.8 m/s^2

$$q_{\phi 50} = 8000 \cdot \left((0.05^2 - 0.036^2) \cdot \frac{\pi}{4} \right) \cdot 1.23 \cdot 1.33 \cdot 9.8 = 121.26 N/m$$

$$q_{\phi 30} = 8000 \cdot \left((0.03^2 - 0.027^2) \cdot \frac{\pi}{4} \right) \cdot 1.23 \cdot 1.33 \cdot 9.8 = 17.22 N/m$$

The direction of the force is the same than the speed car advance and with the opposite direction of acceleration of the vehicle as it is a reaction to progress.

-Weight of the pilot.

In the 95% of the casses, the mass of the pilot is taken M = 75 Kg, and in this case also it will be taken of 75 Kg. Therefore, the weight of the pilot will be M·g and it will applied in the four brackets that the seat is supported. It is shown below.

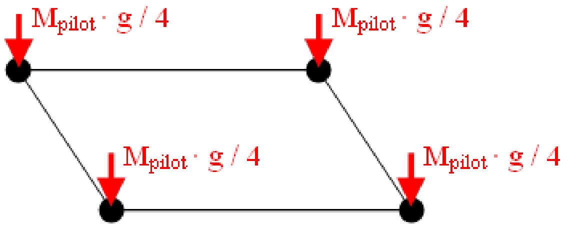


Figure 27: Weight of the pilot

$$F=\frac{M_{pilot}\cdot g}{4}=\frac{75\cdot 9.8}{4}=183.75N$$

-Weight of the engine.

Using the equations of statistics:

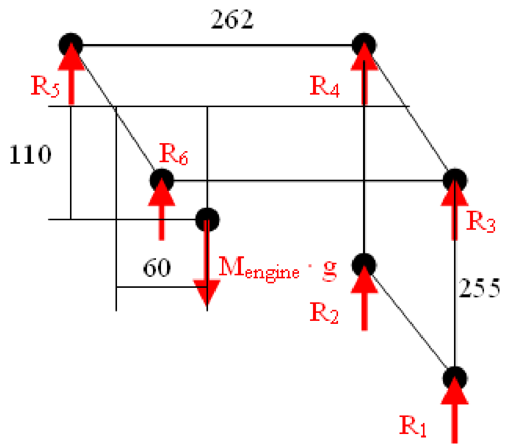


Figure 28: Weight of the engine

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

$\Sigma Fx = 0$ $\quad R_{12} + R_{34} + R_{56} = M_{eng}\cdot g\cdot\gamma$

$R_{12} = R_{34}$

$2\cdot R_{12} + R_{34} = M_{eng.}\cdot g\cdot\gamma$ (1)

$\Sigma M_G = 0$ $\quad R_{56}\cdot 60 = R_{12}\cdot 202 + R_{34}\cdot 202$

$R_{56}\cdot 60 = 2\cdot R_{12}\cdot 202$

$R_{56} = 6.73\cdot R_{12}$ (2)

Substituing (2) into (1):

$$2\cdot R_{12} + 6.73\cdot R_{12} = M_{eng.}\cdot g\cdot\gamma$$

$8.73 \cdot R_{12} = M_{eng.} \cdot g \cdot \gamma$

$$R_{12} = \frac{M_{eng.} \cdot g \cdot \gamma}{8.73} = \frac{105 \cdot 9.81 \cdot 1.33}{8.73} = 156.77N$$

$R_{56} = 6.73 \cdot 156.77 = 1055$ N

$$R_1 = R_2 = R_3 = R_4 = \frac{R_{12}}{2} = \frac{156.77}{2} = 78.38N$$

$$R_5 = R_6 = \frac{R_{56}}{2} = \frac{1055}{2} = 527.5N$$

-Weight of the chassis itself.

The density of steel is 8000 Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value.

$$q_{\phi 50} = 8000 \cdot \left((0.05^2 - 0.036^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 98.6N/m$$

$$q_{\phi 30} = 8000 \cdot \left((0.03^2 - 0.027^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 17.82N/m$$

-Load transfer

$$Wf' = Wf + \frac{h_G}{L} \cdot \frac{W}{g} \cdot A_x \cdot g = 208.1 \cdot 9.8 + \frac{320.26}{2800} \cdot \frac{520}{9.8} \cdot 1.23 \cdot 9.8 = 2112.5N$$

$$Wr' = Wr - \frac{h_G}{L} \cdot \frac{W}{g} \cdot A_x \cdot g = 311.9 \cdot 9.8 - \frac{320.26}{2800} \cdot \frac{520}{9.8} \cdot 1.23 \cdot 9.8 = 2983.4N$$

8.2.3. WHEN THE CAR IS CORNERING

-Inertia of the pilot on the seats brackets.

It is assumed that the effort is applied on the seats brackets and not on the seat belt brackets. It is a left turn, and then the distribution of the loads is as shown.

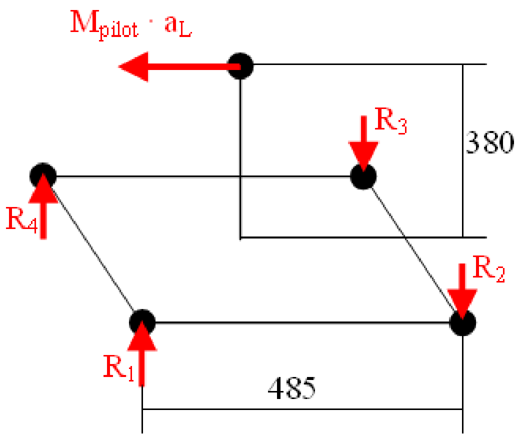


Figure 29: Inertia of the engine cornering

M_{engine}= 105 Kg

a_L = 1.5 m/s^2

Safety factor γ = 1.33

$R_{14} = R_1 + R_4$; $R_1 = R_4$

$R_{23} = R_2 + R_3$; $R_2 = R_3$

$\Sigma F_y = 0$ $\quad R_1 + R_4 = R_2 + R_3$; $R_{14} = R_{23}$

$\Sigma M_{23} = 0$ $\quad R_{14} \cdot 485 = M_{pilot}\, g\, a_L\, \gamma \cdot 380$

$$R_{14} = \frac{M_{pilot}\, g\, a_L\, \gamma \cdot 380}{485} = \frac{75 \cdot 1.5 \cdot 9.8 \cdot 1.33 \cdot 380}{485} = 1148.9N$$

$$R_1 = R_4 = \frac{R_{14}}{2} = \frac{1148.9}{2} = 574.45N$$

$$R_2 = R_3 = 574.45N$$

-Inertia of the engine on the engine brackets.

When the car is cornering, the engine produces the following reactions on the engine brackets.

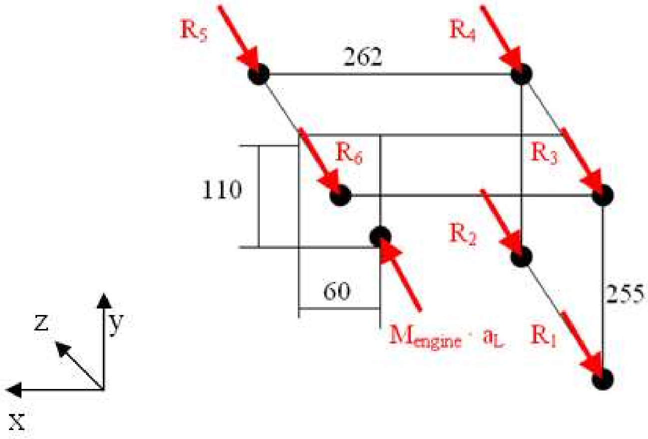


Figure 30: Inertia of the engine cornering

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

$\Sigma F_z = 0$ $\quad R_{12} + R_{34} + R_{56} = M_{eng.} \cdot a_L \cdot g \cdot \gamma$ (1)

$\Sigma M_x = 0$ $\quad R_{56} \cdot 110 + R_{34} \cdot 110 = R_{12} \cdot 145$

$$R_{12} = \frac{R_{56} \cdot 110 + R_{12} \cdot 110}{145} = 0.76(R_{56} + R_{34}) \qquad (2)$$

$\Sigma M_Y = 0$ $\quad R_{56} \cdot 60 = R_{34} \cdot 202 + R_{12} \cdot 202$

$$R_{56} = \frac{R_{34} \cdot 202 + R_{12} \cdot 202}{60} = 3.37 \cdot (R_{34} + R_{12}) \qquad (3)$$

Substituing (2) into (3):

$R_{56} = 3.37 \cdot (R_{34} + (0.76(R_{56} + R_{34}))) = 3.37 \cdot (R_{34} + 0.76 \cdot R_{56} + 0.76 \cdot R_{34})$

$R_{56} = 5.93 \cdot R_{34} + 2.56 \cdot R_{56}$

$R_{56} = -3.8\ R_{34}$ (4)

Substituing (4) into (2):

$R_{12} = 0.76 \cdot (-3.8 \cdot R_{34} + R_{34}) = -2.13 \cdot R_{34}$ (5)

Substituing (4) and (5) into (1):

$-2.13 \cdot R_{34} + R_{34} - 3.8 \cdot R_{34} = M_{eng.} \cdot a_L \cdot g \cdot \gamma$

$-5.93 \cdot R_{34} = M_{eng.} \cdot a_L \cdot g \cdot \gamma$

$$R_{34} = \frac{M_{eng.} \cdot a_L \cdot g \cdot \gamma}{-5.93} = \frac{105 \cdot 1.5 \cdot 1.33 \cdot 9.8}{-5.93} = -346.2N \;\; ; \;\; R_3 = R_4 = \frac{R_{34}}{2} = \frac{-346.2}{2} = -173.1N$$

$R_{12} = -2.13 \cdot R_{34} = -2.13 \cdot (-346.2) = 737.36$ N ; $R_1 = R_2 = \frac{R_{12}}{2} = \frac{737.36}{2} = 368.68N$

$R_{56} = -3.8\ R_{34} = -3.8 \cdot (-346.2) = 1315.48$ N ; $R_5 = R_6 = \frac{R_{56}}{2} = \frac{1315.48}{2} = 657.74N$

-Inertia of the chassis itself.

The density of steel is $\rho = 8000$ Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value:

$$q = \rho \cdot A \cdot d \cdot \gamma \cdot g$$

Where:

q = Density of the steel = 8000 Kg/m^3

A = Area of tube section (m^2)

a = Acceleration of the car (m/s^2)

γ = Safety factor = 1.33

g = Acceleration of the gravity = 9.8 m/s^2

$$q_{\phi 50} = 8000 \left((0.05^2 - 0.036^2) \cdot \frac{\pi}{4} \right) \cdot 1.5 \cdot 1.33 \cdot 9.8 = 147.9N/m$$

$$q_{\phi 30} = 8000 \left((0.03^2 - 0.027^2) \cdot \frac{\pi}{4} \right) \cdot 1.5 \cdot 1.33 \cdot 9.8 = 21N/m$$

The direction of the force is the same than the speed car advance and with the opposite direction of acceleration of the vehicle as it is a reaction to progress.

-Weight of the pilot.

In the 95% of the casses, the mass of the pilot is taken M = 75 Kg, and in this case also it will be taken of 75 Kg. Therefore, the weight of the pilot will be M·g and it will applied in the four brackets that the seat is supported. It is shown below.

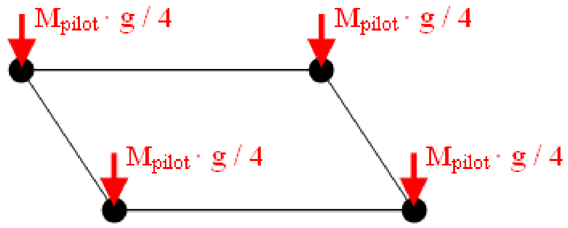


Figure 31: Weight of the pilot

$$F = \frac{M_{pilot} \cdot g}{4} = \frac{75 \cdot 9.8}{4} = 183.75N$$

-Weight of the engine.

Using the equations of statistics:

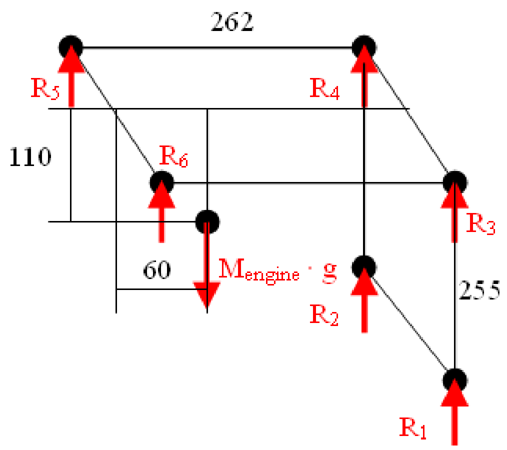


Figure 32: Weight of the engine

$R_{12} = R_1 + R_2$; $R_1 = R_2$

$R_{34} = R_3 + R_4$; $R_3 = R_4$

$R_{56} = R_5 + R_6$; $R_5 = R_6$

$\Sigma Fx = 0$ $\quad R_{12} + R_{34} + R_{56} = M_{eng} \cdot g \cdot \gamma$

$R_{12} = R_{34}$

$2 \cdot R_{12} + R_{34} = M_{eng.} \cdot g \cdot \gamma \quad (1)$

$\Sigma M_G = 0$ $\quad R_{56} \cdot 60 = R_{12} \cdot 202 + R_{34} \cdot 202$

$R_{56} \cdot 60 = 2 \cdot R_{12} \cdot 202$

$R_{56} = 6.73 \cdot R_{12} \quad (2)$

Substituing (2) into (1):

$2 \cdot R_{12} + 6.73 \cdot R_{12} = M_{eng.} \cdot g \cdot \gamma$

$8.73 \cdot R_{12} = M_{eng.} \cdot g \cdot \gamma$

$$R_{12} = \frac{M_{eng.} \cdot g \cdot \gamma}{8.73} = \frac{105 \cdot 9.8 \cdot 1.33}{8.73} = 156.77 N$$

$R_{56} = 6.73 \cdot 156.77 = 1055$ N

$$R_1 = R_2 = R_3 = R_4 = \frac{R_{12}}{2} = \frac{156.77}{2} = 78.38 N$$

$$R_5 = R_6 = \frac{R_{56}}{2} = \frac{1055}{2} = 527.5 N$$

-Weight of the chassis itself.

The density of steel is 8000 Kg/m^3. It must be applied a distributed load in all bars modeled less on which modulate the steering, the engine and the transmission. The distributed load has the following value.

$$q_{\phi 50} = 8000 \cdot \left((0.05^2 - 0.036^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 98.6 N/m$$

$$q_{\phi 30} = 8000 \cdot \left((0.03^2 - 0.027^2) \cdot \frac{\pi}{4} \right) \cdot 1.33 \cdot 9.8 = 17.82 N/m$$

-Load transfer

$$Wfl' = Wf + \frac{h_G}{width} \cdot \frac{W}{g} a_l \cdot g = 208.1 \cdot 9.8 + \frac{320.26}{1750} \cdot \frac{520}{9.8} \cdot 1.5 \cdot 9.8 = 2182.1N$$

$$Wfr' = Wf - \frac{h_G}{width} \cdot \frac{W}{g} al \cdot g = 208.1 \cdot 9.8 - \frac{320.26}{1750} \cdot \frac{520}{9.8} \cdot 1.5 \cdot 9.8 = 1896.63N$$

$$Wrl' = Wr + \frac{h_G}{width} \cdot \frac{W}{g} al \cdot g = 311.9 \cdot 9.8 + \frac{320.26}{1700} \cdot \frac{520}{9.8} \cdot 1.5 \cdot 9.8 = 3203.5N$$

$$Wrr' = Wr - \frac{h_G}{width} \cdot \frac{W}{g} al \cdot g = 311.9 \cdot 9.8 - \frac{320.26}{1700} \cdot \frac{520}{9.8} \cdot 1.5 \cdot 9.8 = 2909.6N$$

8.2.4. WHEN THE CAR SUFFER A CRASH

For the calculation of the crash situation, the regulation of the championship says that the chassis must support the following loads:

-2 times the weight of the car laterally.
-6 times the weight of the car longitudinally.
-6 times the weight of the car vertically.

The weight of the car is 450 Kg, so the car must support the following loads in the crash situations.

$L_{lateral} = 450 \cdot 9.8 \cdot 1.33 \cdot 2 = 11730.6$ N
$L_{longitudinal} = 450 \cdot 9.8 \cdot 1.33 \cdot 6 = 35191.8$ N
$L_{vertical} = 450 \cdot 9.8 \cdot 1.33 \cdot 8 = 46922.4$ N

9. THEORIES OF CALCULUS

9.1. MAXIMUM SHEAR STRESS THEORY OR TRESCA CRITERIA

States that the flow of material is produced by the shear, arose from the observation of the necking that occurs in a specimen when subjected to a tensile test. The theory says: "The failure occurs when the absolute maximum shear stress in the workpiece is equal to or greater than the absolute maximum shear stress of a specimen subjected to a test tensile when occurs the creep".

For an item under the efforts action, we have the following Mohr circle:

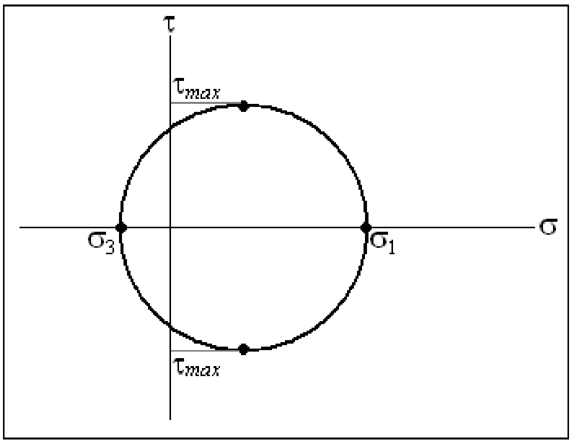


Figure 33: Mohr´s circle for an item

The absolute maximum shear stress is then:

$$\tau_{\max} = \frac{\sigma_1 - \sigma_3}{2} \quad \text{Equation 6}$$

Mohr's circle for the tensile test at the time of flow is:

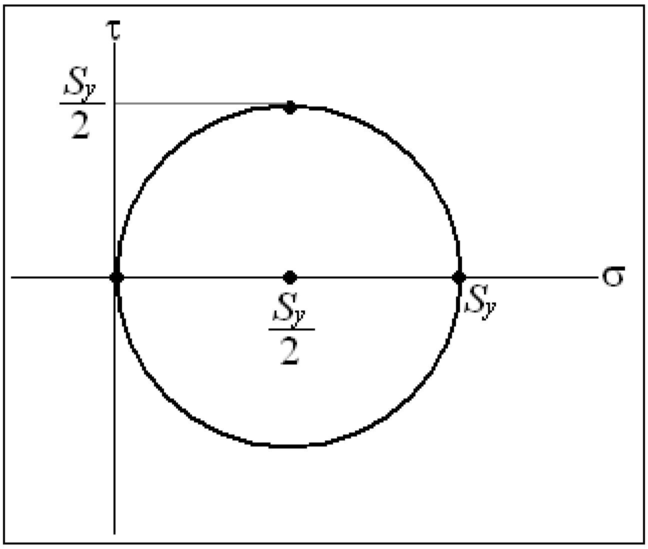


Figure 34: Mohr's circle for the tensile test at the time of flow

The absolute maximum shear stress is then for the tensile test at the time of creep:

$\tau_{\max} = \frac{S_y}{2}$ Equation 7

As says the Tresca´s criteria, equaling the equations 2.1 and 2.2, we have:

$\frac{\sigma_1 - \sigma_3}{2} = \frac{S_y}{2}$ Equation 8

$\sigma_1 - \sigma_3 = S_y$ Equation 9

Equation 2.3 is used when $\sigma_1 > 0 > \sigma_3$. In the other cases:

$\sigma_1 = S_y$, when $\sigma_1 > \sigma_3 > 0$

$\sigma_3 = -S_y$, when $0 > \sigma_1 > \sigma_3$

In the plane $\sigma_1 - \sigma_3$, the Tresca´s criteria is represented graphicly as:

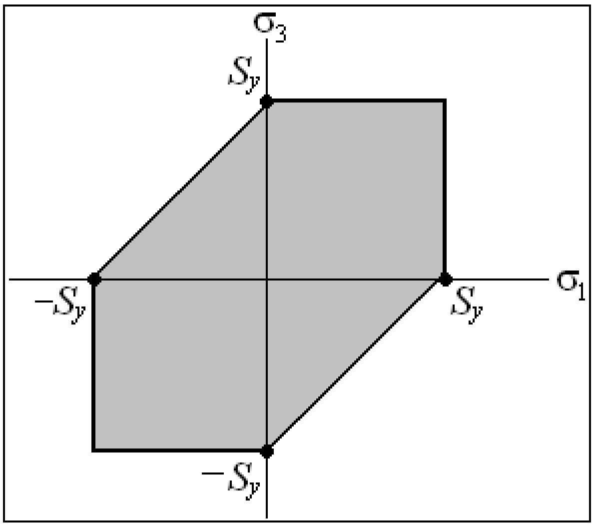


Figure 35: Tresca´s criteria graphic representation

The failure occurs when the point determined by the efforts σ_1 and σ_3 is outside the shaded area in the Figure.

9.2. THEORY OF THE DISTORTION ENERGY OR VON MISSES

Given by R. Von Misses when he saw that the materials under hydrostatic efforts supports much more effort than their yield stresses under other loading conditions. The theory says:

"The failure occurs when the distortion energy per unit volume due to the absolute maximum stresses at the critical point is equal to or greater than the distortion energy per unit volume of a specimen in the tensile test at the time of creep ".

Von Misses theory says that the distortion of the element is due to principal efforts by subtracting the hydrostatic efforts $\left(\sigma_h = \dfrac{\sigma_1 + \sigma_2 + \sigma_3}{3}\right)$. The energy of distortion is the difference between the total strain energy per unit volume and strain energy per unit volume due to hydrostatic efforts.

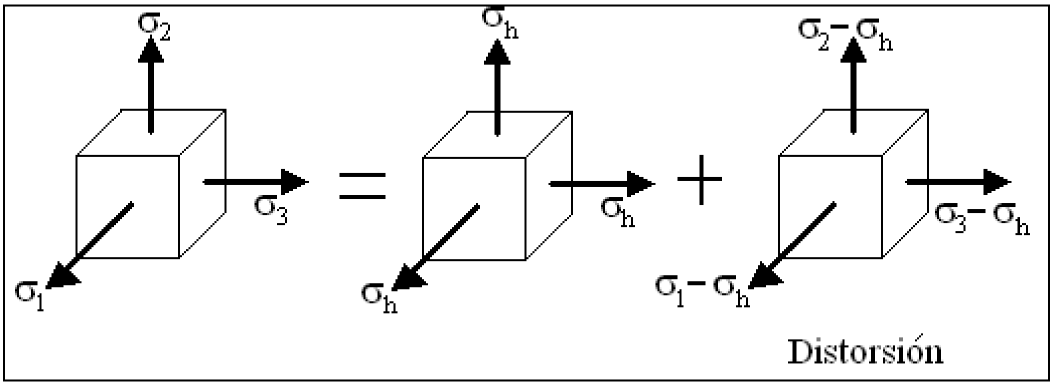


Figure 36: Distortion energy

As the material is in the elastic range (because the failure occurs when reaching the plastic zone), the total strain energy per unit volume for the element is.

$$U = \frac{1}{2}\sigma_1\varepsilon_1 + \frac{1}{2}\sigma_2\varepsilon_2 + \frac{1}{2}\sigma_3\varepsilon_3 \qquad \text{Equation 10}$$

The deformation is:

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} = \frac{1}{E}\begin{bmatrix} 1 & -v & -v \\ -v & 1 & -v \\ -v & -v & 1 \end{bmatrix} \cdot \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{bmatrix} \qquad \text{Equation 11}$$

Replacing the deformations of the ecuation 11 in the ecuation 10, the deformation total energy is:

$$U = \frac{1}{2E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2v(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3)\right] \qquad \text{Equation 12}$$

The deformation energy due to hydrostatic efforts is:

$$U_h = \frac{3(1-2v)}{2E}\sigma_h^2 = \frac{3(1-2v)}{2E}\left(\frac{\sigma_1 + \sigma_2 + \sigma_3}{3}\right)^2 \qquad \text{Equation 13}$$

The distortion energy is then:

$U_d = U - U_h$ Equation 14

$U_d = \frac{1}{2E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2v(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3)\right] - \frac{3(1-2v)}{2E}\left(\frac{\sigma_1 + \sigma_2 + \sigma_3}{3}\right)^2$ Equation 15

$U_d = \frac{1+v}{3E}\left(\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3\right)$ Equation 14

En el ensayo de tracción cuando se produce la fluencia, $\sigma_2 = \sigma_3 = 0$, $\sigma_1 = S_y$ and then the energy of distortion in the specimen is:

$U_d = \frac{1+v}{3E} S_y^2$ Equation 15

Equaling the equations 2.9 and 2.10 as says the theory, we have:

$\frac{1+v}{3E}\left(\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3\right) = \frac{1+v}{3E} S_y^2$ Equation 16

$\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3} = S_y$ Equation 17

$\sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}} = S_y$ Equation 18

The effort of Von Misses is defined as:

$$\sigma' = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}}$$

Equation 19

Where $\boldsymbol{\sigma_1}$, $\boldsymbol{\sigma_2}$, $\boldsymbol{\sigma_3}$ are the main stresses of the stress state, with its own sign. These main stresses are obtained by the Mohr's circle. In the case of the lengths of the bars used in a chassis, the shear stresses created from the shear stress **Q** are much lower than those produced from the axial force **N**, the torque **T** and the bending moment **M**. Given this, the worst stress state would be the next.

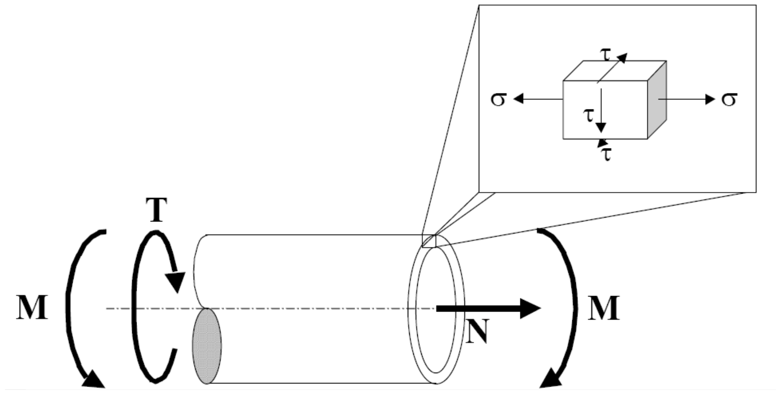


Figure 37: *Stress state of the bars.*

Where $\sigma = \frac{N}{A} + \frac{M \cdot \frac{D}{2}}{I}$ Equation 20 $\tau = \frac{T \cdot \frac{D}{2}}{I_p}$ Equation 21

One of the planes of the element under consideration will have the following stress state:

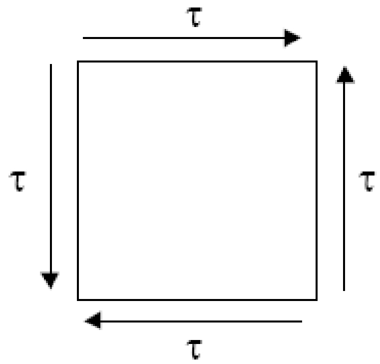


Figure 38: Stress state, plane 1.

If it is made a 45 degrees turn, in the same plane, the equivalent stress state will be the next:

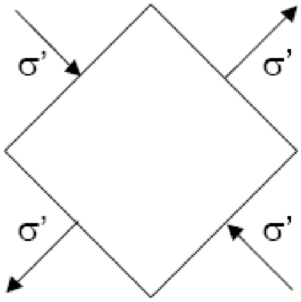


Figure 39: Oblique's view of the stress state.

With this plane and these two pictures it can be found the first Mohr's circle.

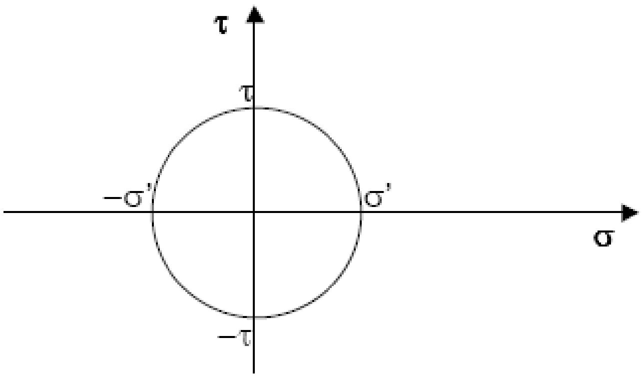


Figure 40: First Mohr's circle

The stress state of the perpendicular planes is the next:

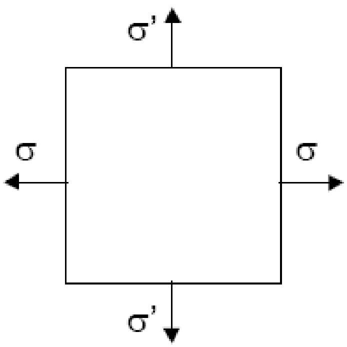


Figure 41: Stress state, plane 2

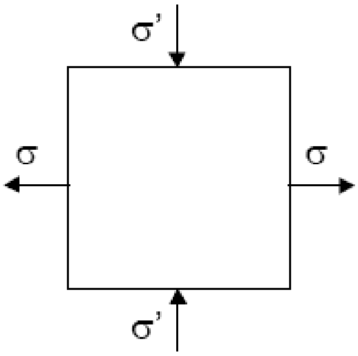


Figure 42: Stress state, plane 3

These stress states have their following corresponding Mohr circles.

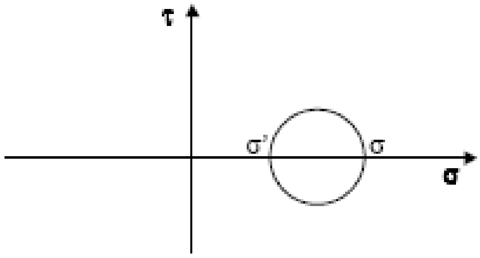


Figure 43: Second Mohr's circle

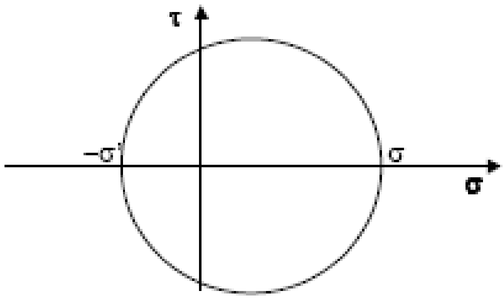


Figure 44: Third Mohr's circle

Therefore, it follows that the set of Mohr circles is:

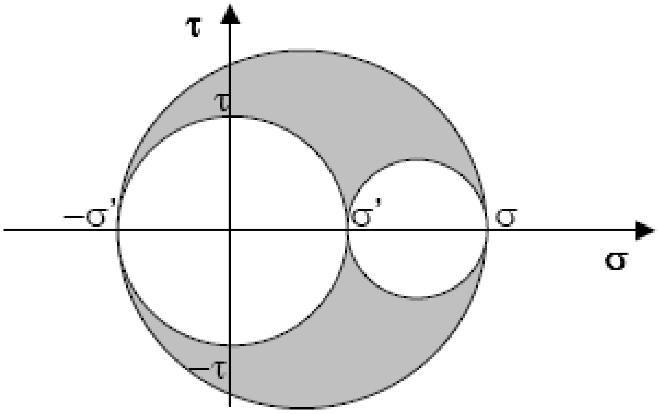


Figure 45: Set of Mohr circles

The possible stress states are those belonging to the shaded area. Therefore, it is obtained:

$$\sigma_1 = \sigma = \frac{N}{A} + \frac{M \cdot \frac{D}{2}}{I} \quad \text{Equation 22}$$

$$\sigma_2 = \tau = \frac{T \cdot \frac{D}{2}}{I_p} \quad \text{Equation 23}$$

$$\sigma_2 = -\tau = -\frac{T \cdot \frac{D}{2}}{I_p} \quad \text{Equation 24}$$

If these expressions are substituted in the Von Mises (σ_{VM}) expression:

$$\sigma_{VM} = \sqrt{\left(\frac{N}{A} + \frac{M \cdot \frac{D}{2}}{I}\right)^2 + 3\left(\frac{T \cdot \frac{D}{2}}{I_p}\right)^2} \quad \text{Equation 25}$$

Then, the failure occurs when $\sigma = S_y$.

For the two-dimensional case, $\sigma_2 = 0$, the Von Misses effort will be:

$$\sigma' = \sqrt{\sigma_1^2 + \sigma_3^2 - \sigma_1\sigma_3} \quad \text{Equation 26}$$

And it is represented graphically as:

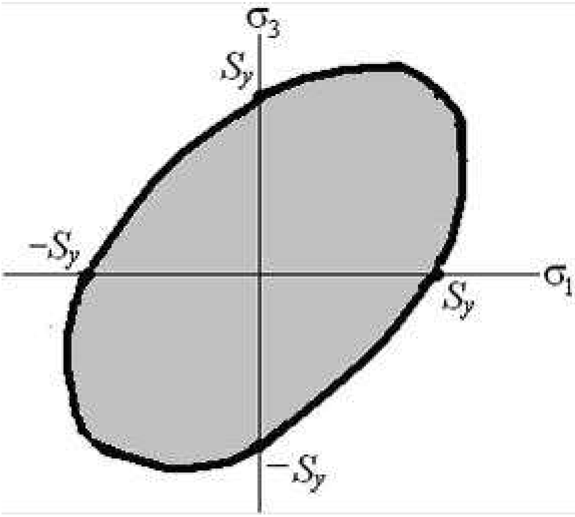


Figure 46: Graphic representation of distortion energy´s theory

The failure occurs when the point determined by the efforts σ1 and σ3 is located outside of the shaded area.

9.3. CHOOSING OF METHOD FOR THE CALCULATIONS OF CHASSIS

In Figure 47 is shown that the Von Mises theory has a larger area in which no occurs failure comparing to Tresca criteria, so the maximum shear stress theory, this is, Tresca criteria, is the theory chosen to make conservative estimates of failure of a material and have greater certainty that failure will not occur.

In this project, for calculate the validity of the chassis, submited to different efforts, it will use the theory of the maximum shear stress , because is more conservative, and we want to be sure that the chassis is going to support the efforts, and in this way, ensure the security of the pilot.

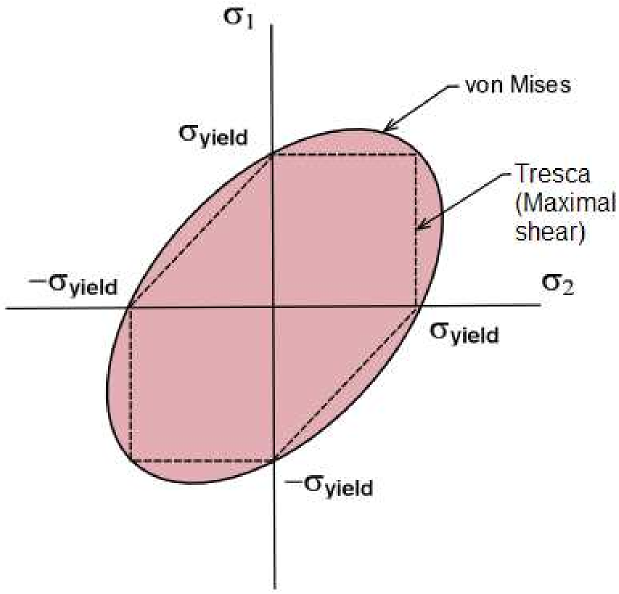
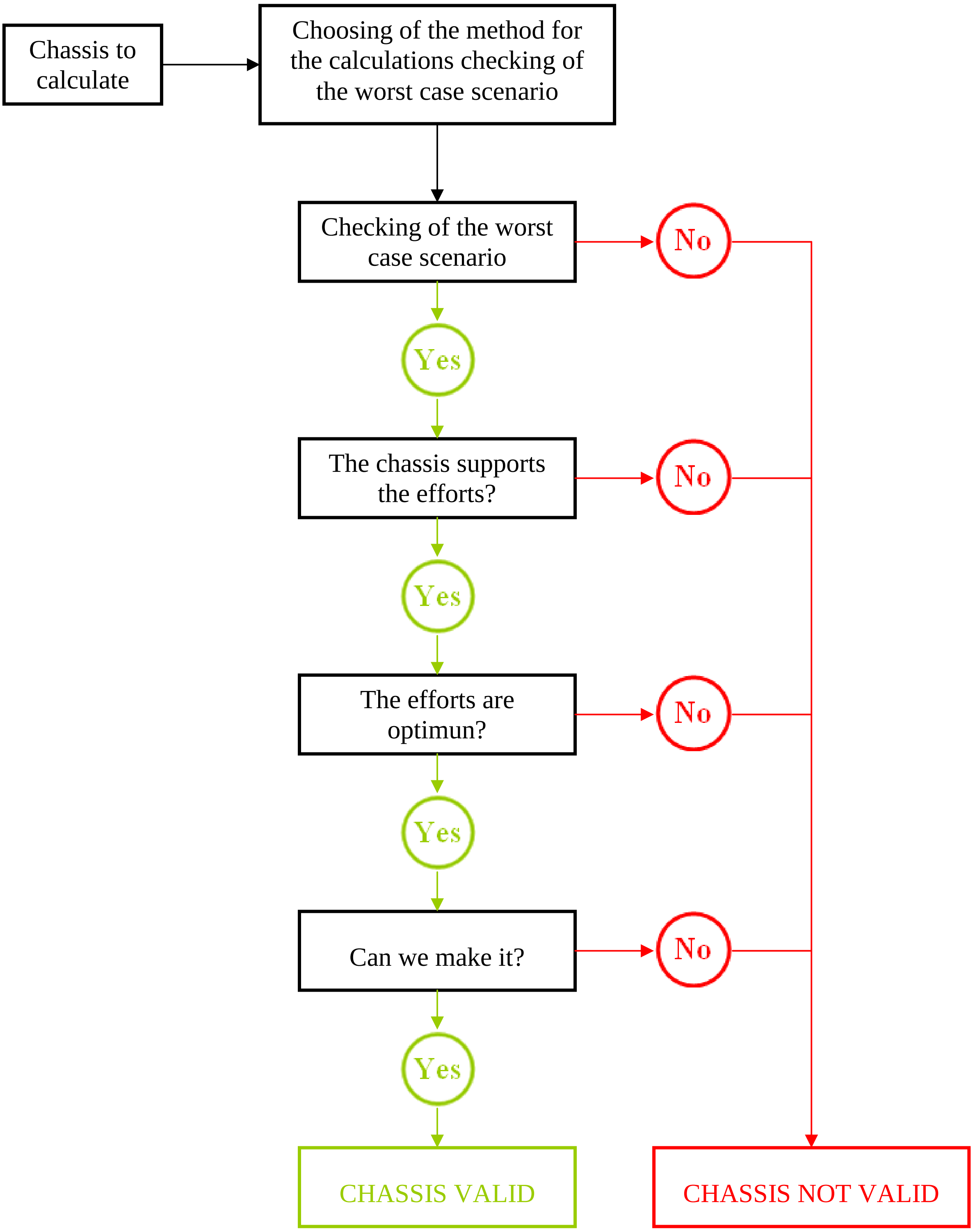


Figure 47: Failure sith Von Mises and Tresca

10. ALGORITHM FOR CALCULATION OF A TUBULAR CHASSIS



11. CALCULATION OF THE CHASSIS

11.1. CORNERING SITUATION

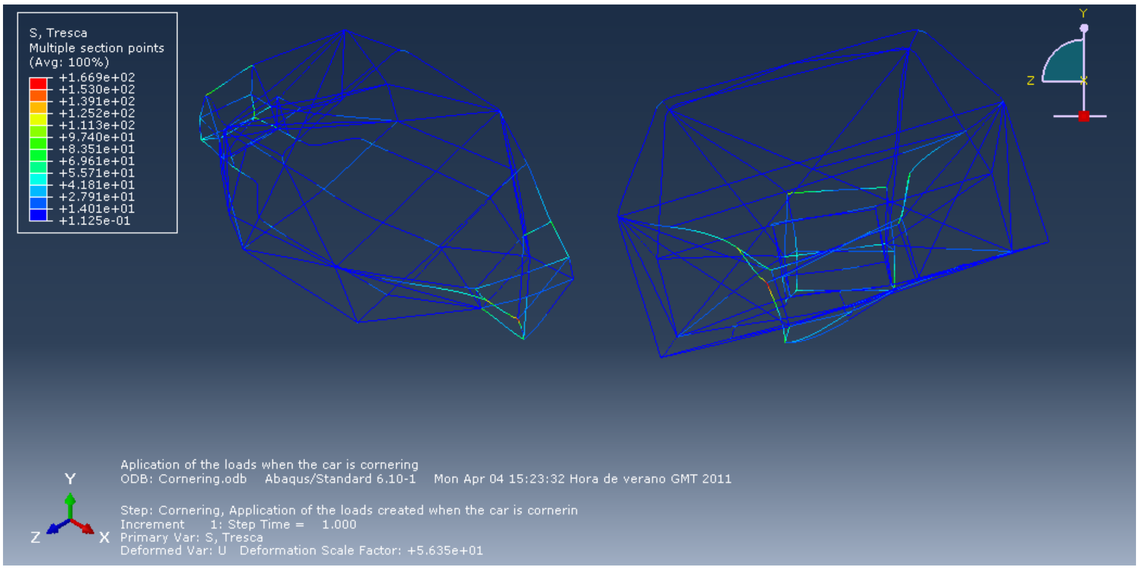


Figure 48: Tresca tensions when cornering

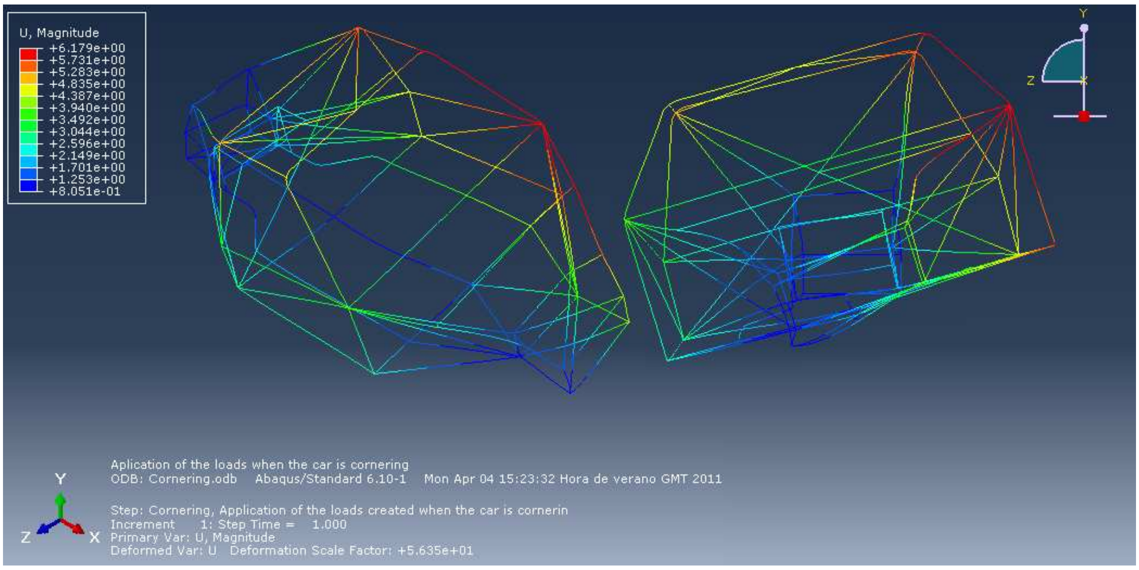


Figure 49: Displacement of nodes when cornering

11.2. VERTICAL CRASH

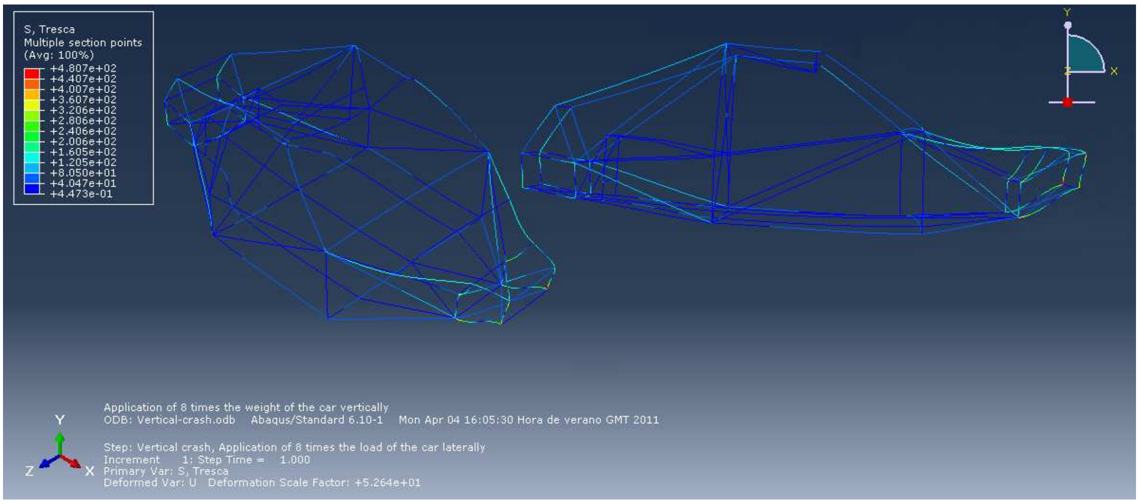


Figure 50: Tresca tensions when vertical crash

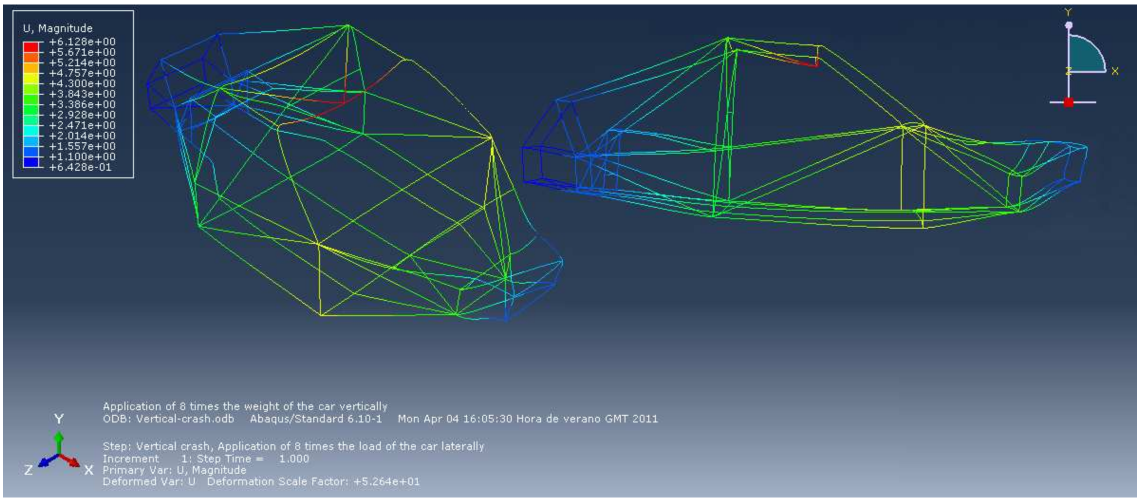


Figure 51: Displacement of nodes when vertical crash

11.3. LONGITUDINAL CRASH

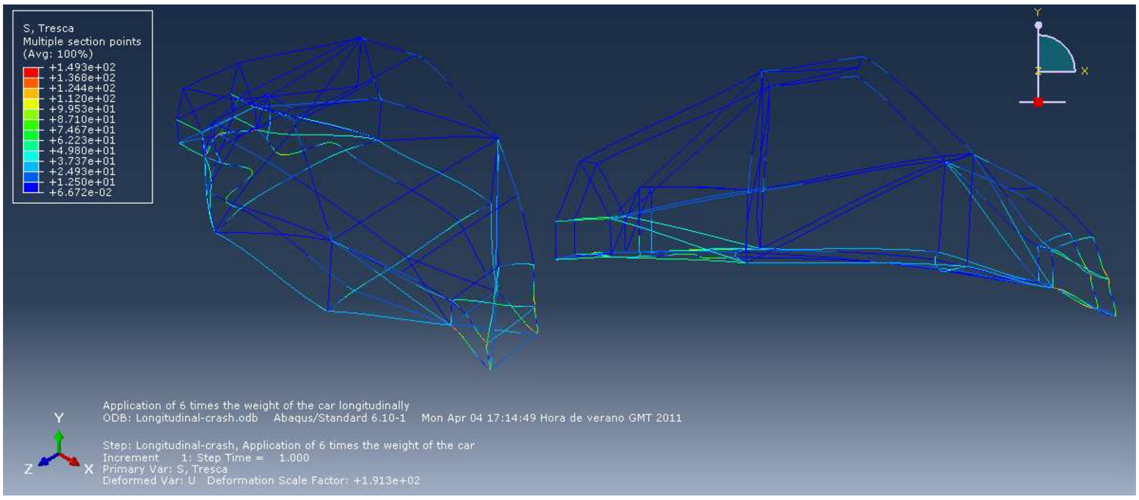


Figure 52: Tresca tensions when longitudinal crash

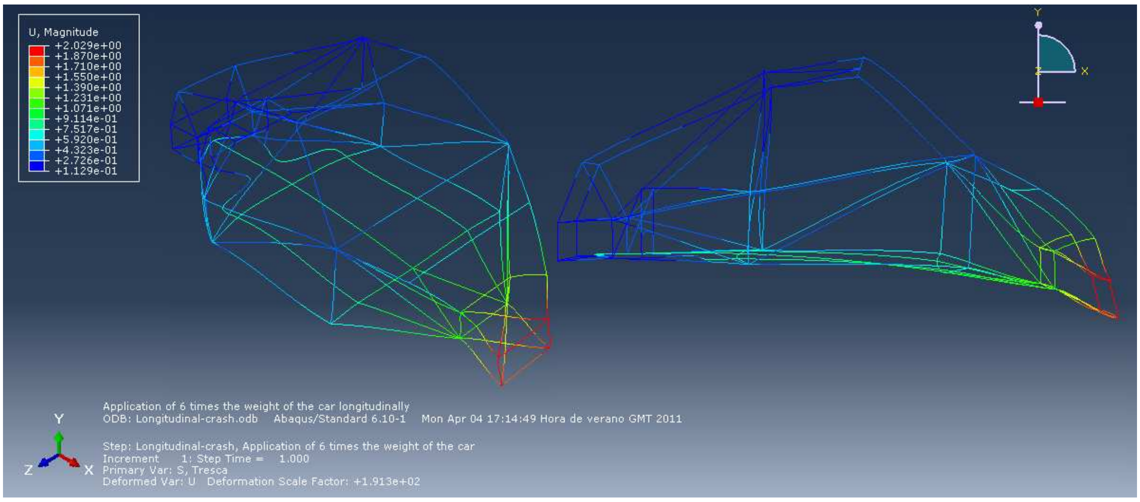


Figure 53: Displacement of nodes when longitudinal crash

11.4. LATERAL CRASH

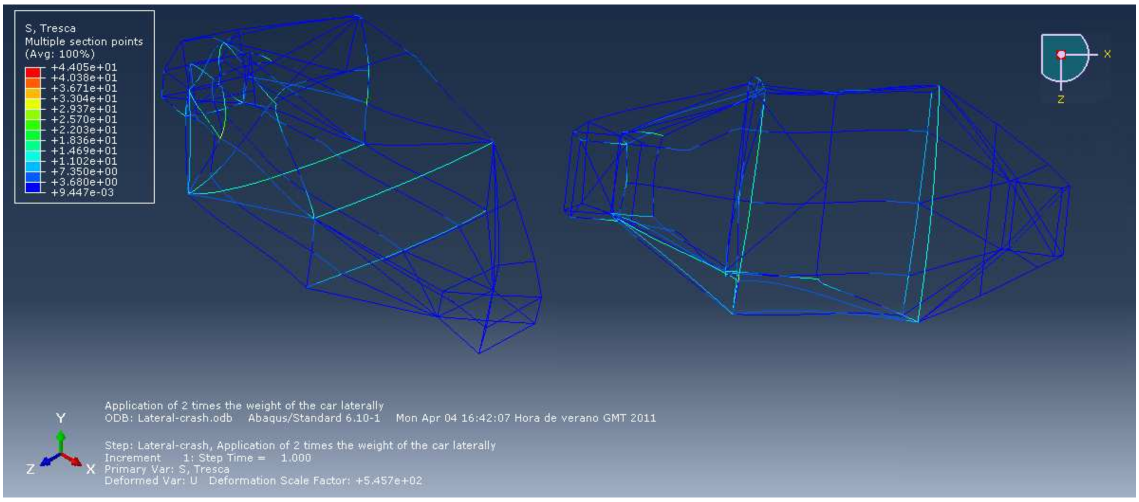


Figure 54: Tresca tensions when lateral crash

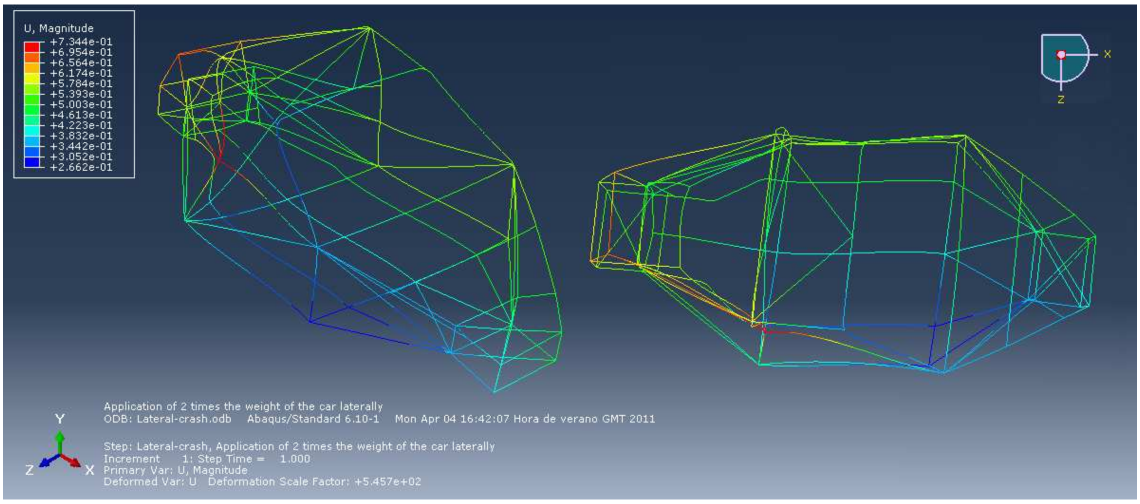


Figure 55: Displacement of nodes when lateral crash

12. ANALYSIS OF THE RESULTS AND CONCLUSIONS

12.1 CORNERING SITUATION

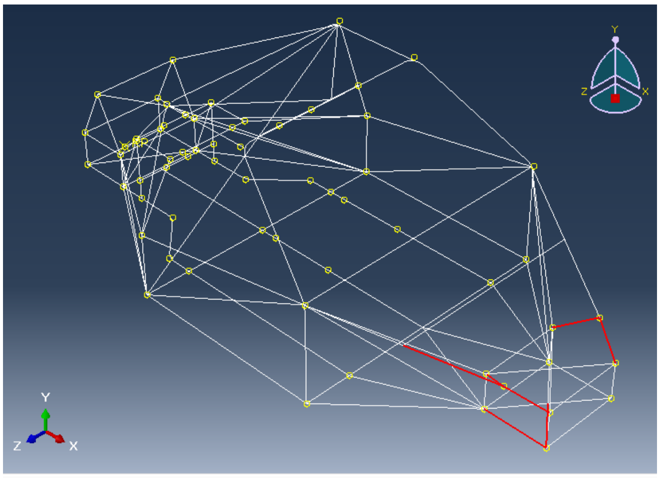


Figure 56: The tubes with maximun tension when cornering

In the cornering situation, the tubes that most suffer are the shown in the picture above. These tubes, reach the maximun tension of 159 MPa, but only in one point. The rest of the zones of the tubes, suffer more or less 100 MPa tension, which is not very high, taking in account that the material can support 265MPa, this is the 38% of the capacity of the tube. It means, that only we would have elastic deformation in the tubes.

Besides, taking in account that all the loads applied in to the chassis for simulate the cornering situation, have a security factor of 1.33, the chassis must support the tensions created in the chassis without any problem.

The cornering situation, is the worst case scenario in normal race conditions. Knowing this, we can see that the chassis can support this case, so that, we know that the chassis also is going to support the loads created in the acceleration or braking situations.

In the cornering situation, we have obtained deformations of 6 mm on one side of the car. At first view, it seems too much, but taking in account the boundary conditions applied in the car for the simulation, we have left freedom in the chassis for the torque, and due to lever exists from the bottom part of the chassis to the high part, the results are not very real and should actually be much lower. Also, is very difficult to have this deformations in the chassis, because before suffer deformation, the car would loose contact in the closer side to the center of the curve.

12.2. VERTICAL CRASH

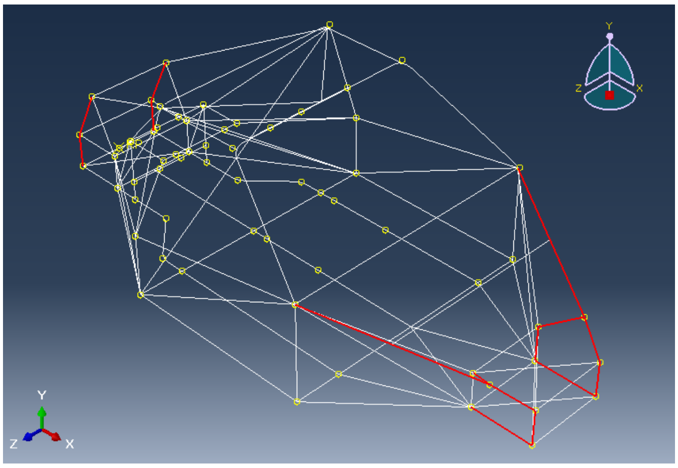


Figure 57: The tubes with maximun tension when vertical crash

The vertical crash situation, is the most demanding situation according to the rules of the spanish mountain championship. The regulation requires that the chassis must support 8 times the weight of the car vertically, and the deformations can not be more than 50 mm.

In the picture above, are marked in colour red the tubes that suffer the most. These tubes are working in higher tension than 265 MPa, reaching in some zones more than 450 MPa. It means, that in these zones, the elastic limit of the material is exceeded, and we have plastic deformation. This is very bad for the car, because we need to make big reparation, but it does not matter, because the main objective of this proyect is to garanty the security of the pilot, and for that, is better to have plastic deformations in the front or back parts of the chassis, absorbing in this way the most energy of the colision by this deformation, and then transmitting the less energy as possible to the cockpit, no resulting it damaged and ensuring the safety of the pilot.

12.3. LONGITUDINAL CRASH

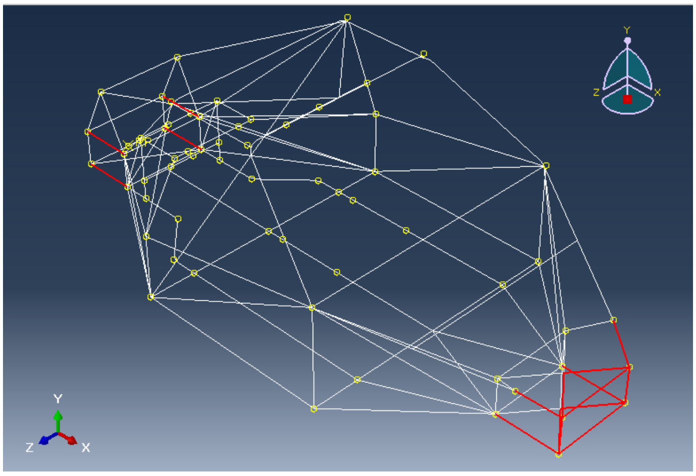


Figure 58: The tubes with maximun tension when longitudinal crash

The longitudinal crash situation, is the second more demanding situation according to the rules of the spanish mountain championship. The regulation requires that the chassis must support 6 times the weight of the car longitudinally, and the deformations can not be more than 50 mm.

In the picture above, are marked in colour red the tubes that suffer the most. These tubes are working in higher tension of more or less 125 MPa, reaching in som zones 150 MPa. This tensions are the 45% of the capacity of the material. According to the spanish mountain championship rules, we meet them, but suposing that the crash is worst, and we reach tensions that causes plastic deformations in the bars, the first part to deform is the front part, absorbing the most energy of the impact the front part, due tu this tubes have smaller section, for be less strength than the cockpit, and therefore, to ensure the safety of the pilot.

12.4. LATERAL CRASH

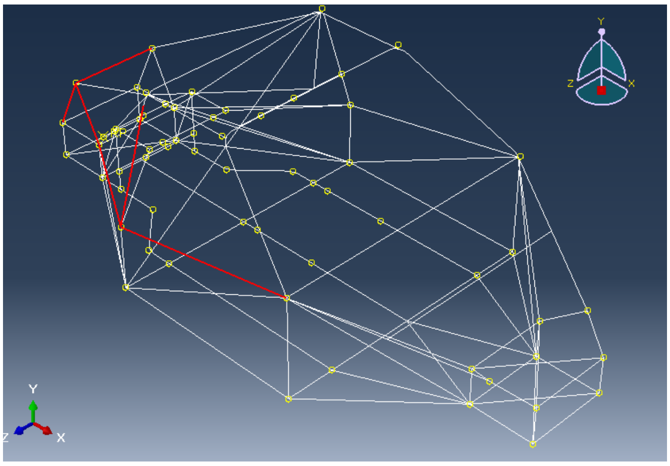


Figure 59: The tubes with maximun tension when lateral crash

The lateral crash situation, is the less demanding situation according to the rules of the spanish mountain championship. The regulation requires that the chassis must support 2 times the weight of the car laterally, and the deformations can not be more than 50 mm.

In the picture above, are marked in colour red the tubes that suffer the most. These tubes are working in a tension of 42 MPa. This tensions are the 16% of the capacity of the material. Firstly, there are no problems to support lateral crashes, but suposing that the lateral crash is too hard, this bars would be the the first to deform, and as there are an important part of the cockpit, we can have troubles. However, the part of the maximun deformation of the chassis is the right part, and as the pilot is situated in the left, the safety of the pilot is guaranteed, because in the back of the pilot, is situated a lateral tube for the anchorage of the belts, and at the same time, it makes lateral strength, avoiding the lateral deformation of the chassis in the position of the pilot.

13. CONCLUSIONS

At the time of design the chassis of a car, the key for obtain a good design, is the definition of the most important points of the chassis correctly, and after, adapt the distribution of the tubes to these points. In this way, we ensure that the design of the chassis will be optimun.

The main conclusion of this proyect is that there is no a completely automatable method to desigh and calculate a chassis. To design it, is needed to be creative to take decisions at the time to make changes into the design, to solve the problems appeared in the procces and obtain the best solution possible.

Using the software Abaqus, the calculation process is greatly reduced, and it is easy to simulate the chassis submited to a different efforts, but is not very easy to define the boundary conditions, to obtain the more realistic results as possible. However, at the time to simulate with different materials, changing the material properties, we obtain new results quickly, and the work is decreased significantly.

14. FUTURE LINES OF WORK

The chassis has been designed taking into account only the considered static and dynamic loads. When driving, it is obvious that, in the vehicle, appear vibrations due to the efforts from the field have different distribution. This will make that the chassis can fail to fatigue.

The design of the kart has been done taking into account only the weight of the pilot, the weight of the engine, and every loads caused by the weight of the chassis itself. A complete would be the one which takes into account the suspensions, transmission, steering, etc… According to the motorsport magazines, the chassis should absorb these efforts. To absorb these efforts, the chassis should be deformed. This requires that certain areas of the chassis should have relatively small stiffness. At this point, it is reached a contradiction with what has been seen in this project, so, a balance between rigidity and flexibility on the different areas of the chassis should be done. Another point that should have been studied is the determination of the applicable load assumptions due to aerodynamic forces.

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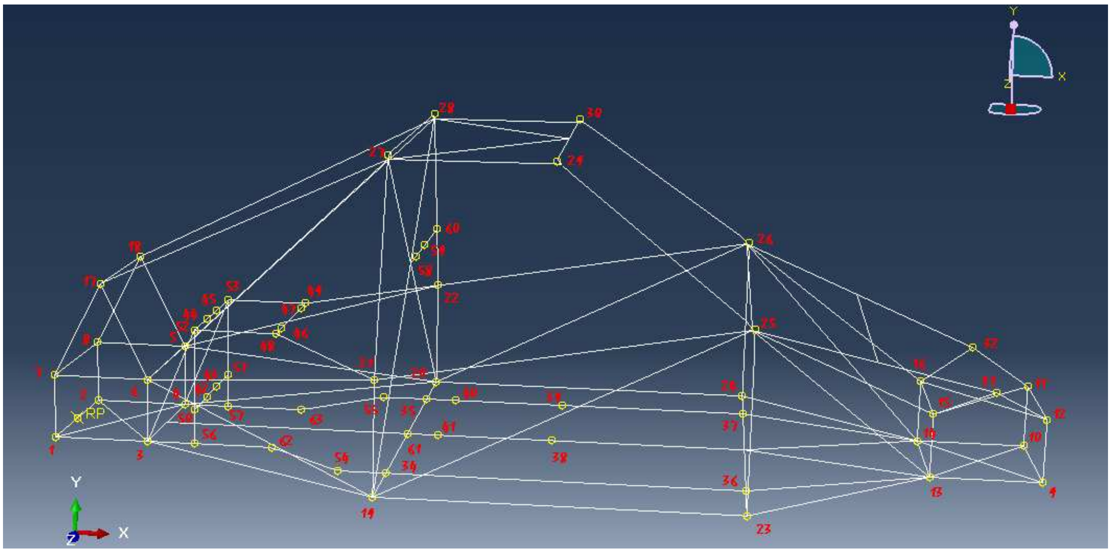
APPENDIX A: KEY POINTS OF THE CHASSIS



POINT	X	Y	Z	POINT	X	Y	Z
1	0	0	250	32	2950	300	-325
2	0	0	-250	34	1100	0	485
3	300	0	250	35	1100	0	-485
4	300	0	-250	36	2200	0	485
5	300	200	-250	37	2200	0	-485
6	300	200	250	38	1575	0	0
7	0	200	250	39	1575	0	-485
8	0	200	-250	40	1200	0	-485
9	3125	0	225	41	1200	0	0
10	3125	0	-225	42	450	110	72.5
11	3125	200	-225	43	450	110	-72.5
12	3125	200	225	44	450	365	72.5
13	2775	0	225	45	450	365	-72.5
14	2775	0	-225	46	712	365	166
15	2777	200	225	47	712	365	-166
16	2775	200	-225	48	712	265	250
17	150	500	250	49	712	365	-250
18	150	500	-250	50	450	110	250
19	1100	0	750	51	450	110	-250
20	1100	0	-750	52	450	365	250
21	1100	350	750	53	450	365	-250
22	1100	350	-750	54	950	0	485
23	2200	0	750	55	950	0	-485
24	2200	0	-750	56	450	0	250
25	2200	550	750	57	450	0	-250
26	2200	550	-750	58	1100	561.355	-132.5
27	1100	980	550	59	1100	561.355	-352.5
28	1100	980	-550	60	1100	561.355	-682.9
29	1600	980	550	61	1100	0	0
30	1600	980	-550	62	700	0	250
31	2950	300	325	63	700	0	-250

APPENDIX B: SPEED CAR TECHNICAL REGULATION

1) RULES

1.1. Any change that is not explicitly authorized in this Technical Regulation or any of its attachments is prohibited.

1.2. Approval Sheet is the document that certifies the validity of all vehicle components.

1.3. Vehicles involved in Cup, must comply with the regulations contained in these Regulations. Contestants are responsible for their vehicle is in full compliance at all times of the test. To do so, shall submit to TK if required, the approval form issued by the RFEDA. and the workshop manual and / or spare parts catalog motorcycle manufacturer's production, which is released its powertrain (no kits will be allowed special pieces to increase the performance of the bike in question, or parts catalogs drawn from other officers).

1.4. Titanium use is prohibited (unless it is used in the standard engine mounting).

1.5. With respect to the chassis, will only be allowed the only metal monocoque, or tubular, not being authorized yarn of "honeycomb"metallic, rather than for flat bottom and front enclosure required.

2) ENGINE

2.1. The engine is limited to 1,000 cm3 and a maximum of 4 cylinders.

2.2. The RFEDA established a deadline of April 1, 2006 for vehicle manufacturers could apply for approvals-CM as an alternative option VO-jet engine from a dealer sold the brand to set a date to 31/12/06.

2.3. These approvals were valid for the years 2007 and 2008.

2.4. For the next period (2009 and 2010), the rules stated that CM vehicle manufacturers could submit requests for approval in the last quarter of 2008. The validity of these began on January 1, 2009.

3) BODYWORK AND DIMENSIONS

3.1.

a) The maximum length of the vehicle may not exceed 3,750 mm.

b) The overall width of the vehicle may not exceed 1,750 mm.

c) The height measured vertically from the lowest point of the flat surface to the highest point of the vehicle must not exceed to 1,030 mm saving security the main arc will not result in a streamlined structure.

d) The maximum cantilever measured from the trapezium axle to the end of the vehicle must be 730 mm in the front axle and 630 in the rear axle.

3.2. The dimensions of the bottom must be such that you can enter a rectangle or parallelogram of 500 mm in total length and 300 mm high measured vertically in the corners will be rounded to a maximum of 150 radio mm. Vehicles which are sliding doors will not be admitted unless they are a safety device that allows accident quickly and easily evacuate the occupants of the vehicle.

The doors must bear a distinct window of the bottom panel, held in a transparent material which may contain a horizontal parallelogram with sides of at least 400 mm. Height measured on the surface of the window perpendicular to the horizontal sides is at least 250 mm. The angles of the parallelogram can be rounded according to a radius of 50 mm. Shall be so designed as to not restrict the driver's side view. Each door should not take more than an external handle shall be of the type of cam driven up, clearly marked with a red arrow or a color that contrasts with the background. Only the driver's door can be fitted with an approved network, in which case the glass is not required as described above.

3.3. You must mount a windscreen made from a single piece of laminated glass or polycarbonate 4 mm thick. The shape of this glass has to be such that at a distance of 50 mm measured vertically from the base of the upper point of the transparent, glazed surface has a length of at least 250 mm measured on the line, on a part and a longitudinal axis of the vehicle. Its top edge should form a regular and continuous convex line with the horizontal plane. Must be enrolled in it, a vertical strip of 100 mm and 850 mm long (measured horizontally) on the rope between the faces of the windshield.

3.4.

1. Prohibited the use of carbon fiber and / or Kevlar in the manufacture of the body, but the rear aerodynamic devices consist of a wing including its support, may be made of these composite materials. Is understood as wing-shaped surface profile inverted airplane wing, separated from the surface formed by the body so that an airflow can pass between these two surfaces.

2. The body should cover all mechanical components, with the sole exception of the intake and exhaust outlets.

3. The air intake inlet, you can not rise above the final curve of the roll bar.

4. Between the back edge of the front wheels complete, and the front edge of the rear wheels complete the entire visible suspended from the underside of the vehicle has to be a solid, continuous flat and continuous, which is possible to fit a rectangle 1000 mm (measured by the transverse axis of the vehicle) by 800 mm (measured along the longitudinal axis of the vehicle) (tolerance + - 5 mm).

5. No part of this area will have an aerodynamic influence and no part of the body may be in no event below the plane formed by the surface geometry defined above in Article 3.4.4.

6. All parts having aerodynamic influence, as well as any of the body must be fixed rigidly to the sprung part of vehicle (chassis whole body) should not have any

possibility of movement, be attached firmly and remain stationary with respect to that part when the vehicle is moving.

7. Any device or construction, designed to stand between the sprung part of vehicle and the ground is prohibited.

8. Behind the rear wheels, the body must fall below the axis of said rear wheels. Every opening of cooling performed in the body and directed backwards, be provided with shutters or other device to prevent the vision in any case, the mechanical and the wheels. The body must cover the wheels, so that it covers at least the top of its circumference.

9. All body panels must be complete and carefully finished, no interim pieces covering previous damage.

10. The mountings of the front and rear hoods, must be clearly indicated by arrows in red or another color that contrasts with the background of the body and must be used without aid of tools.

11. Taking into account the projection of the body in a horizontal position from the axis of the front wheels drag any item in horizontal projection exceed more than 200 mm. It allows the addition of a horizontal plane at the front (split) of a maximum width of 50 mm., measured from the projection of the original body on the ground forward. Should be extended the lower plane, noticed him and the car body without inserts. Their lateral width may not exceed the body.

12. Is allowed a wing of one plane of maximum section 250 mm. x 150 mm., and the value length of the vertical projection of the body on the horizontal plane, less than 75 mm. on each side, if it were curved, the maximum length is 500 mm. The end of the wing must be parallel to the longitudinal axis of the vehicle and have a maximum dimension of 280 x 160 mm. and thickness 5 mm.

4) WEIGHT

4.1. Empty: Vehicles must weigh a minimum of 445 kg in the following conditions: The fuel tank empty, and the level of lubricating oil required. It will allow a maximum total tolerance + - 3 kg

In race: In race conditions with the pilot on board, the total weight must not be less than 550 kg

4.2. To achieve this minimum weight ballast may be used with the condition of being fastened to the carrier, and must bear a seal of the RFEDA placed by the Scrutineers. A burden that is not sealed, not to be taken into account when weighing if verification.

4.3. It is forbidden to be replaced during the race, a structural element of other heavier vehicles in order to meet the minimum required weight.

5) ENGINE / GEAR BOX

5.1. Engine

1. The engine must come from a bike series as has been described in Section 2. The inlet 4 in the head, carry rings restrictors or so-called restrictor flange. The placement of the flow restrictor flange intake air in the ducts of the cylinder head must be done outside of the pipes of the water head above them, in the ducts carrying butterflies. Must be firmly fixed (banded) to them, according to the drawing shown below, with a maximum of 31 mm throat. in diameter. The gorge of the Rings restrictors should be extended to over 3 mm. according to the design that adjunta.El method of checking the tightness of the system of admissions made by dabbing the 4 inputs of the intake air with the motor at 3,500 rpm, in which case the engine should stop within 3 seconds. In the picture you can see the inner ring cylindrical shape, and minimum inside dimensions of 31 x 3 mm which is the bridle. They must meet the following conditions:
Point A represents the axis of butterflies mechanically by the accelerator. The B, which is powered butterflies should be kept in its original position himself drawn on convenience. It can however remove these butterflies, preventing any additional air

intake shaft. From the center of the middle axis of the throat of the flange should be a maximum of 110 + / - 5 mm.

The way upstream and downstream of the restrictor ring is always free interior is maintained as described (freeform areas in the figure). The flange must be sealed by TK externally by passing a wire and a seal, or a touch of paint on an exterior screw to prevent be removed without violating it. As mentioned above, the total air admitted by the engine for combustion of the fuel-air mixture must pass through the rings restrictors located as previously described. Any additional air intake should be sealed permanently.

2. Prohibits any type of spray water inside or outside or any other fluid than the mandatory commercial gasoline, the engine air intake.

3. Is prohibited from any device, construction, or design, whose purpose is the reduction of air temperature on admission.

4. The material, type and number of engine mounts are free, as well as its position and inclination within the compartment. The original ignition system must be maintained. The brand and type of spark plugs, the limiting regime as well as on the ramp are free.

5. The lubrication system is free provided the content is up to six liters.

6. The cooling radiator and its pipe to the engine, the thermostat and ventilation system are free and the place of location. If using a water pump outside the engine can be free, but if used in it, should be the standard.

7. You may modify the elements that control the engine carburetor, may change the dosage of fuel provided but not the amount of air. The system shall be retained and must therefore keep the carbs if the original amount, or injection, if so equipped as standard, but the entire system of air filter, air box etc. upstream of the carburetor or intake ducts is free on condition of their same functions. Prohibited the intake variables whatever their class.

8. Switchboard: standard, except as permitted below.

The outside unit should be strictly the same as standard motor bike great series that is derived, and the installation wiring that connects all the peripherals to it, is free. The programming also is free, is allowed to modify the ignition distributor or computer (ECU) in respect of progress maps or injection, if this is electronic, so that the forward curve, or injection map are tailored to the needs of the engine . Should be kept the same number of sensors and actuators, input and output source. An engine should start and maintain idle speed, serial unit now in an investigation mounted by replacing the contestant. It allows you to override the channels that are used exclusively for the services of the bike which is derived (step, actuators, butterfly, etc.)..

9. The original motorcycle exhaust can be changed or adjusted by the manufacturer, who must approve and shape in the approval form submitted to the RFE A. Must comply with articles relating to the body and safety. The maximum permissible sound level measured according to the general specifications of the championships in Spain is 110 db.

10. The exhaust outlet should be located in the vertical plane of the vehicle rear end. The outlets for the rear, must be located between 450 mm and 100 mm from the ground. In the case of lateral, shall be advanced from the vertical plane through the whole motor-gearbox, and not over the body.

11. The gasket should have the same thickness as the original amount, although the material is free. The resulting final compression ratio should not exceed that specified by the manufacturer in the Workshop Manual.

12. Is it possible to remove all elements of the gas recirculation system, the gasoline vapor recovery systems, recycling of oil vapors. In the event that this deletion leaves a hole open, it must be plugged or sent to a decanter Cofano located in the rear motor-vehicle-which must have a minimum capacity of 2l.

13. Butterflies of progression can be canceled both as an appropriate operation in a fixed position. In the event that a conduit is set aside, should not generate an additional air intake after the intake flange.

5.2. Gear Box

1. The maximum number of speeds, is limited to 6, in the case of having the ability to select a different step speeds (reducing), is not to be operable from the cockpit, in addition, all vehicles must be equipped with a reverse to be selected at any time of the test by the driver seated normally behind the wheel with the engine running and used normally. The reverse may be mounted either inside the original box, as in a specific investor for the march.

2. Are prohibited and semi-automatic gearboxes.

3. Transmission to the rear wheels can be done either by chain or shaft drive / tree or pine nuts. In the case of chain-done, it must be effectively protected.

4. The original pinion gear box is free. But it is forbidden to change the ratio of the speed gears, except for the reverse assembly required, in which case it could eliminate one of the relations of origin.

5.3. The number of clutch discs and linings are free with the sole exception of carbon material, but must be approved by the vehicle manufacturer.

5.4. Differential. It is free and can be installed a limited slip, will be prohibited pneumatic control, electronic or hydraulic.

6) SUPPLY SYSTEM

6.1. Gasoline used should be of commercial use and agree to the specifications of the championships and trophies in Spain.

1. Storage is prohibited in the vehicle fuel or abroad aimed at reducing the fuel temperature 10 º C below ambient temperature.

2. Air can only be used as fuel combustion.

3. Fuel pipes must have a minimum burst pressure of 41 bar and a minimum operating temperature of 135 º C. If you are flexible pipes and bolted joints must have a cover woven steel mesh flame resistant.

4. No driving fuel must pass through the occupant compartment, he may be in any filter or fuel pump.

5. All fuel lines shall be located so that a possible leak can not produce an accumulation or entry of fuel into the cockpit.

6. The atmosphere made the fuel tank must be equipped with rollover valves activated by gravity.

7. The fuel pumps must be operated only when the engine is running, debiéndose off power to the pumps if they are electric.

6.2. Fuel Tank

1. The security deposit can not be placed more than 65 cm from the longitudinal axis of the vehicle and must be located within the limits defined by the axes of front and rear wheels. The maximum capacity must be 20 liters, and be built under the 1999 or higher FT3 specifications and supplied by an approved manufacturer. Shall be provided with a window that allows the manufacturer to see the specifications under which they were built, and date of manufacture. No deposit is to be used more than 5 years from that date, unless inspected and recertified by the manufacturer for a period of up to another 2 years.

2. Filling holes should not protrude from the bodywork, should seal, and its closure should be designed so as to avoid accidental opening.

7) SUSPENSION

Placed the wheels in contact with the ground, their strategies should be suspended from the whole-body chassis through the suspension (ie the wheel axles must not be connected directly to chassis-body) The suspension should not be constituted by bolts interns, flexible hoses or any type of elastic structure, must have independent movement of the ejesportamanguetas allowing mobility of the suspensions in a vertical direction up and down with superior flexibility to their anchorages. Each wheel shall not be suspended rather than an elastic and a cushion. The elastic elements should be both spring and should be fitted at least one damper shaft. Any other systems derived therefrom, shall be submitted to the Technical Department of the RFE A. for possible approval after consideration.

7.1. Active suspensions are prohibited as well as control systems allowing the flexibility of the springs, the damping force, or the ground clearance of the vehicle when in motion.

7.2. Is prohibited chrome suspension elements.

7.3. The composite materials are prohibited in any part of the suspension.

8) BRAKES

Vehicles must be equipped with at least two separate brake circuits powered by the same pedal. This system must be designed so that in case of leakage or failure in one circuit, the braking action can continue to carry at least two wheels.

8.1. The carbon brake discs are prohibited.

8.2. The brake calipers can not have more than two pistons each and no more than one per wheel. In the event that the clip comes from a production vehicle and is mounted on the knuckle joint of the same car bracket series, admits that there is a maximum of four pistons per caliper if you mount that standard.

8.3. The maximum diameter of the brake discs must be 280 mm.

8.4. It is compulsory to have a usable brake for parking.

9) WHEELS, TIRES, STEERING

9.1. Tires. The maximum permitted width of the throat of the rims is: 7"8.5"the front and the rear.

9.2. The maximum diameter of the same tire front and rear is 13 "

9.3. Tires are banned totally or partially constructed composite materials and / or magnesium.

9.4. The only tires allowed in Spain Cup CM 2010 are Brand AVON down in this article. Necessarily slicks all cars must fit the "slick" brand AVON type A-15, the following measures: 7,2-20,00-13 "in front, and 8,2-22,0-13" behind (6583/4833 front AVON name: 7.2/20.0-13 14 208 A15, rear: 14 209 8.2/22.0-13 A15)

Number of tires to use:
-Free Trainings: The number of tires in use will be free.
-Official Trainings: The maximum number of tires in use will be free.
-Race: The maximum number of tires is four plus one joker.
-Rain tires. Compulsory for all cars are mounting special AVON mark wet type A-15, the following measures: 7,2-20,00-13 "in front, and 8,2-22,0-13" behind (name AVON 14 208 A15 6583/4833 7.2/20.0-13 front and behind: 14,209 8.2/22.0-13 A15). All

carry a rain tires yellow sticker with the initials "EMC" molded material, no scratches. No rain tires are considered the "slick" scratched.

9.5. The following awards are set to hand over the top 5 CM Cup Spain 2010:
1 º Classified. € 6000
2nd Place. € 4000
3rd place. € 2500
4 th position. € 1500
5th place. € 1000

10) COCKPIT

10.1. Establishing the volume of the carrier, should be symmetrical about the longitudinal axis of the vehicle.

10.2. To a height of 300 mm. floor of the vehicle, the driver must be located on one side of the longitudinal axis being the normal driving position.

10.3. The minimum width at the elbows of the pilot, should be of 1,100 mm. maintained at a height of 100 mm and a length of 250 mm. This measure is taken horizontal and perpendicular to the longitudinal axis of the vehicle.

10.4. Legroom

1. The vehicle must have two, defined as two volumes of free and symmetrical longitudinal axis of each of which must have a minimum volume of 750 cm2. This area shall be maintained from the map of the pedals, to the vertical projection of the center of the wheel.

2. The minimum width of the volume of foot position is 250 mm. maintained at a height of at least 250 mm.

3. The plane positioning of the pedals should be such that the pilot with his feet resting

above them does not exceed a vertical plane passing through the center of the front wheels.

10.5. All enclosed vehicles must carry a fresh air inlet and exhaust the air used in the cockpit.

11) SECURITY STRUCTURE S

11.1. Rollover structures. Must be approved by the R.F.E. A., and all the constitutive structure of the chassis.

11.2. Approval of the security structure

For approval by the Federation, must submit a dossier reflecting the following features: The vehicle manufacturer must endorse the security structure to the RFE A., will be composed exclusively of carbon steel tubes cold drawing, with a minimum diameter of main arches 50 x 2 mm., or 45 x 2.5 mm., for all approved vehicles from January 1 2006. In the dossier for approval, shall present a study of strength of materials signed by a qualified practitioner, which demonstrated that the structure resists the following requests:

a) 2 times their weight laterally. (2P)

b) 6 times its weight in both directions longitudinally. (6P)

c) 8 times its weight vertically. (8P)

In this study should be noted that P should be increased in 75Kg.

d) Description of the structure.

e) Certificate of materials used in manufacturing, quality-certified steel tube stockist, analysis of the casting product and tensile test.

f) type of solder used, machine fabrication number and system description, characteristics of the filler material; operator who carried out the welding.

g) Calculation of the resistance of the structure to show that they comply with the above values.

h) At least 12 photographs that appear anchorage areas to different parts of the vehicle, the main hoop, longitudinal and transverse braces, doors etc longitudinal reinforcements.

i) The structure must be identified individually by the manufacturer with a unique number, which must issue a certificate that the bidder submit it to the CC. TT. of proof in the case if required. The structure may not be modified without being subject to other approval by the manufacturer.

11.3. Deformable structures.

1. The bottom of the tanks must be protected by a deformable structure 10 mm in thickness.

2. If the fuel tank is located less than 200 mm of the lateral flanks of the vehicle, its lateral surface must be protected entirely by a deformable structure with a minimum thickness of 100 mm.

3. The deformable structure should consist of a sandwich construction incorporating a core of non-flammable, low resistance to crushing of 18 Newton/cm2 and two layers of at least 1.5 mm thick one in an aluminum alloy whose tensile strength is at least 225 Newton/mm2 and minimum elongation of 5%, or two sheets of 1.5 mm minimum thickness present a minimum tensile strength of 225 Newton/mm2.

4. Deformable structures may not be transferred, nothing more than water pipes but no fuel or oil pipelines or electric cables.

11.4. Fireproof wall and floor

1. Vehicles must be equipped with fireproof wall positioned between the pilot and the engine to prevent the passage of liquids, gases and flames in the engine compartment into the passenger compartment. Any opening in the wall fire protection should also be limited as much as possible, allowing only the right step of the controls and recommended cables later sealing the holes made.

2. The floor of the carrier must be designed so as to protect the driver of stones, oil, water and debris from the engine or projections of other vehicles.

3. The floor and walls of separation, should incorporate a drainage system to avoid any buildup of fluid.

4. The case should include an energy absorbing structure, placed in front of the rider's feet positioned along its entire width. This structure should be independent of the body, and if it is removable, should be firmly attached to the ends of the tubular structures drawers or side of the main chassis (ie with the help of bolts needed to be necessary to use tools to be removed). Must have a minimum length of 30 cm, a minimum height of 15 cm across the vertical section and a section less than 800 cm2 total. This structure must be made of a metallic material with a minimum thickness of 1.5 mm, to submit a minimum tensile strength of 225 N/mm2 and construction sandwich with honeycomb intermediate. Should be a box whose panels have a thickness of 15 mm, or if (the) radiator (s) are integrated into the structure, two adjacent drawers minimum section of 100 cm2 of a party, and one of the radiator (s .) All holes and cuts in this structure should be strengthened, and all sections of the materials in which these holes are made must also conform to the requirements regarding the minimum area of the material. The R.F.E. of A, may approve a type of vehicle structure that meets the same function by itself, in which case it should be expressly included in the homologation of it.

12) SAFETY EQUIPMENT

12.1. Firefighting: The vehicle must be fitted with a FIA approved extinguishing system according to Article 7.2 (installed systems) of Annex J in paragraphs: 7.2.2, 7.2.3, 7.2.4, 7.2.5.

12.2. Seatbelts: Seat belts mandatory, must be type "harness" and agree with the Article 6 of Annex J, paragraphs 6.1, 6.2, 6.3.

12.3. Mirrors: The vehicle must be equipped with two mirrors, one on each side of the vehicle, with a minimum area of 90 cm2.

12.4. Seat. Headrest: The vehicle must be fitted with a headrest with a minimum area of 400 cm2 the surface must be continuous and without any overhang.

12.5. If the seat is not part of the vehicle structure, must be an FIA approved, subject to mandatory anchors according to these same standards.

12.6. Power cuts:The pilot normally seated with seat belts fastened and placed at the wheel, you should be able to cut all electrical circuits and stop the engine by a switch-proof material. The internal switch must be marked by a symbol showing a red spark in a blue triangle bordered white background. Also must have a clearly marked outside shooter in the same way, which can be manipulated by relief workers in case of accident. This handle should be located at the bottom of the stud driver side windshield.

12.7. Towing eye: The vehicle be fitted with a towing eye of an external diameter of 80 mm. affixed to the front and rear structures, the minimum inner diameter is 60 mm. and thickness of 8 mm. shall be painted red or orange and can not stand in the front of the body on the ground level.Anilla de remolque

12.7. Será obligatorio equipar el vehículo con una anilla de remolque de un diámetro exterior mínimo de 80 mm. fijada sólidamente a las estructuras delantera y trasera; el diámetro interior mínimo será de 60 mm. y espesor de 8 mm. deberá estar pintada de un color rojo o naranja y no podrá sobresalir de la proyección vertical de la carrocería sobre el plano del suelo.

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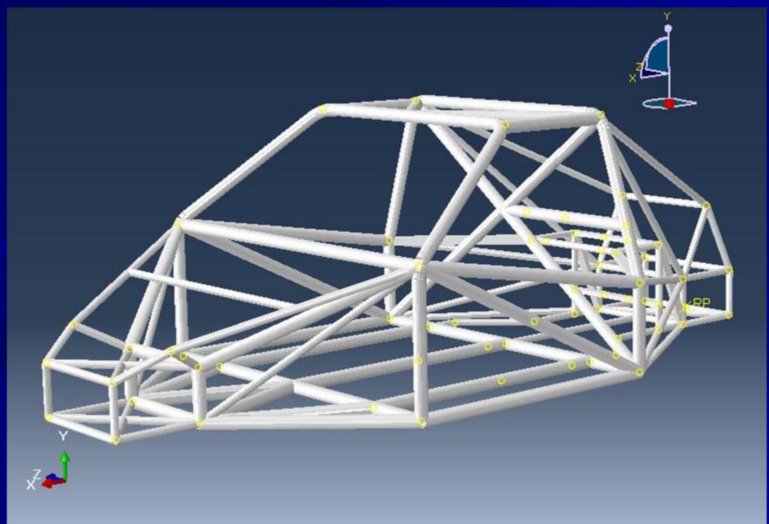
“ANALYSIS OF EFFORTS ON A TUBULAR CHASSIS”



Student: Diego Pérez

Tutor: Olivier Durieux

INTRODUCTION

- What is a Speed Car?

- What is the objective?

  Pilot security

  Cheaper

  Light

  Strong

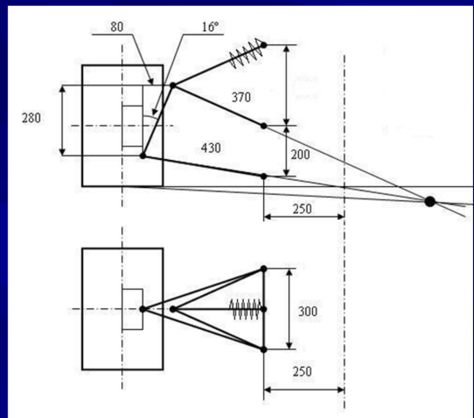
PROCESS

- Define the most important points
- Drawing of the chassis
- Calculation of the loads supported by the chassis
- Design the chassis with Abaqus
- Choose the material
- Choose the calculation theory
- Submit the chassis to the worse case scenario
- Optimize the design
- Check validity

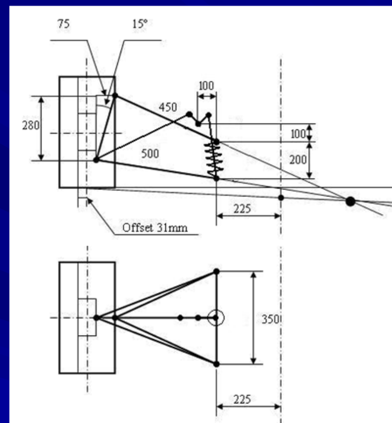
•Definition of the most important points

-Suspension

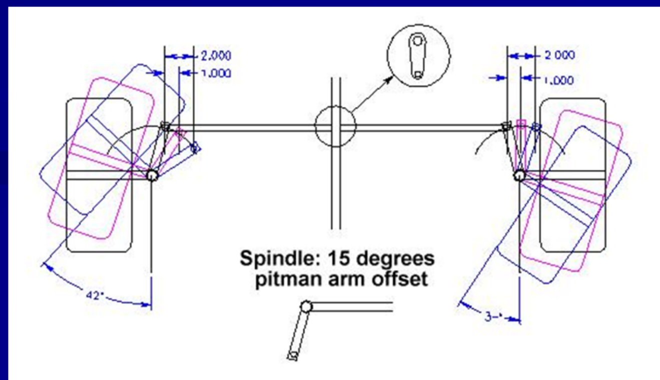
Rear



Front

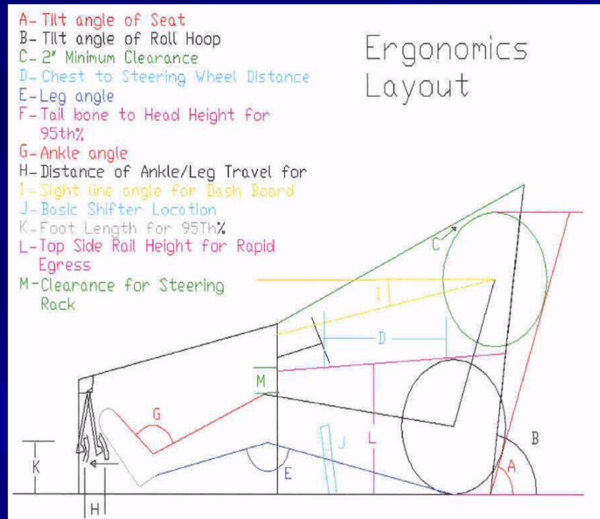


-Direction



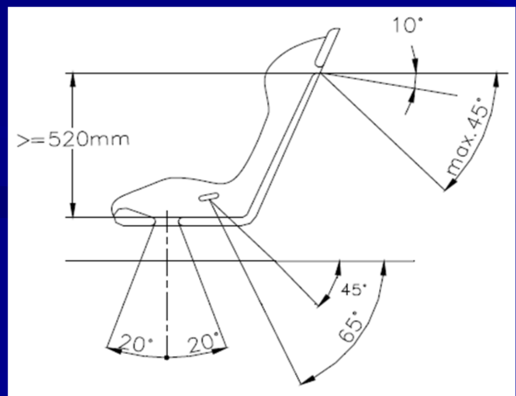
•Definition of the most important points

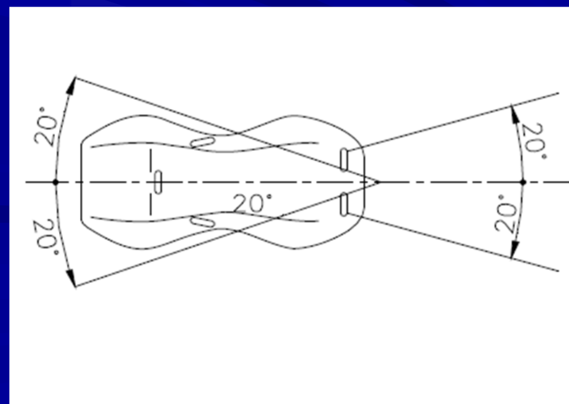
-Space for the pilot



-Anchorage points

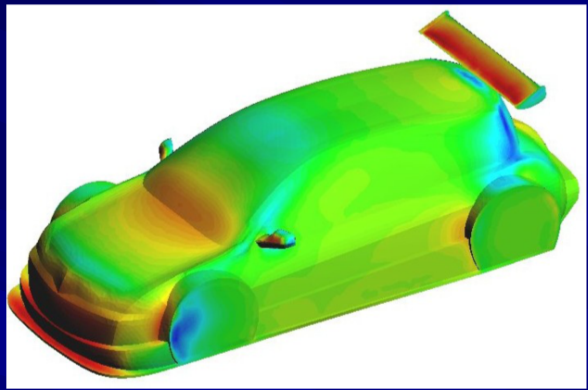
of the belts

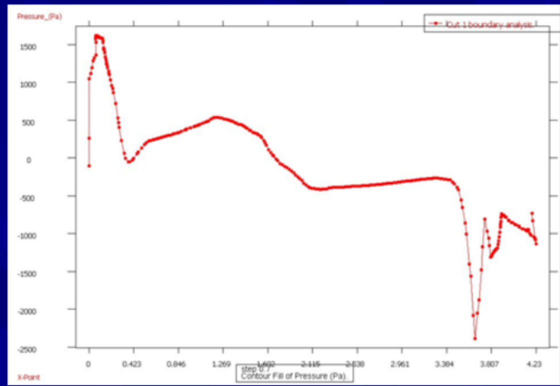




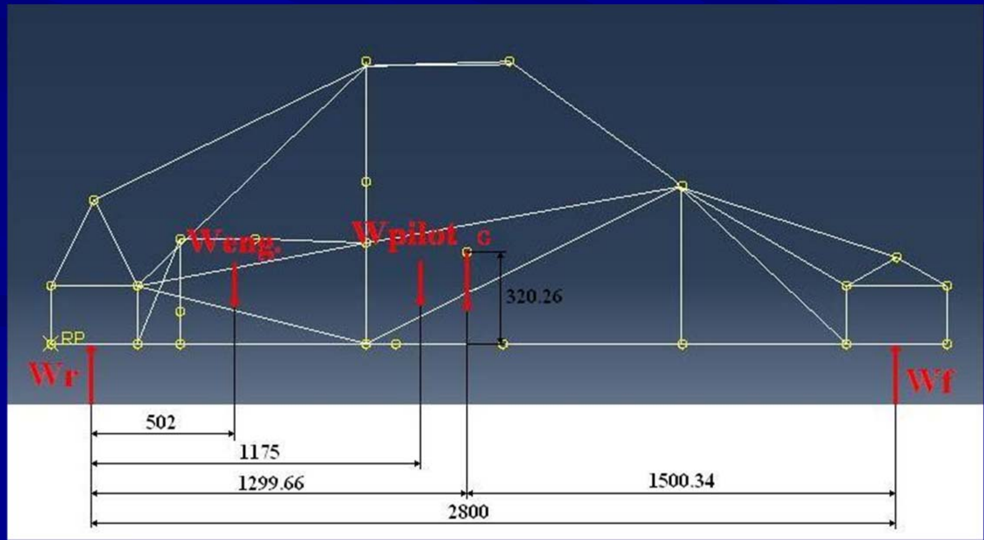
•Definition of the most important points

- Chassis



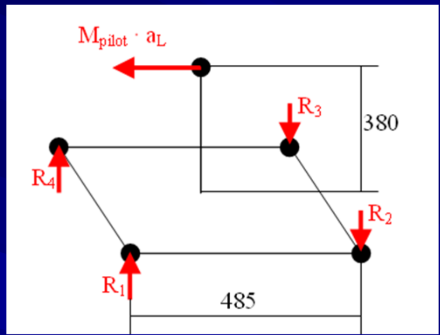


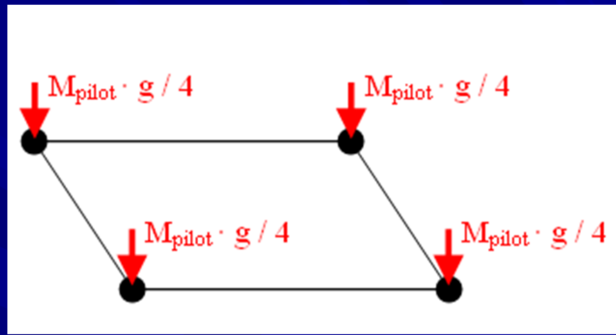
- Center of gravity

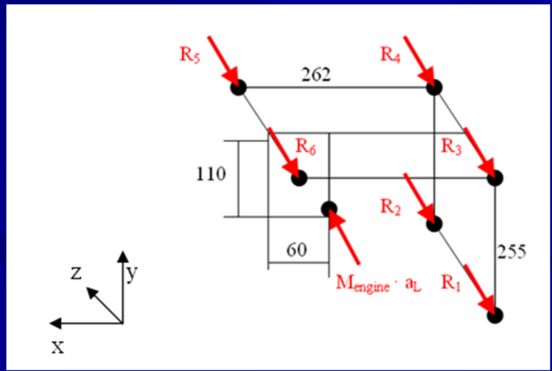


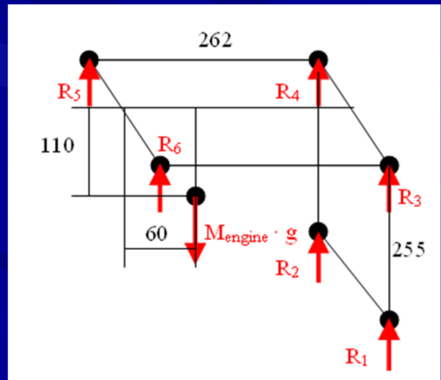
•Calculation of the loads supported by the chassis

- •Weigth and inertyas
  - •Pilot
  - •Engine
  - •Chassis
  - •Load transfer



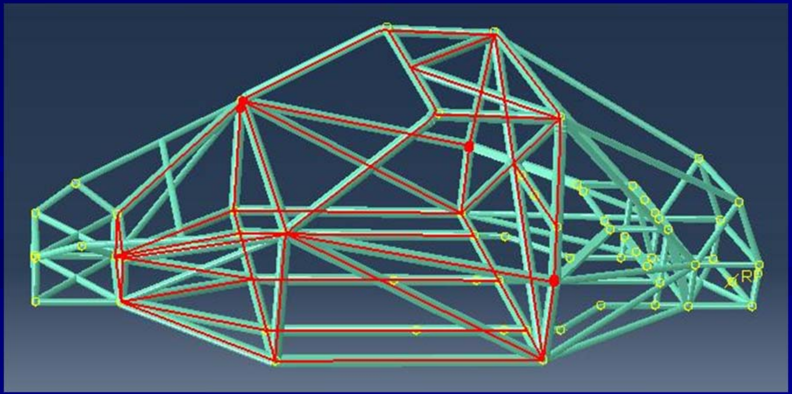




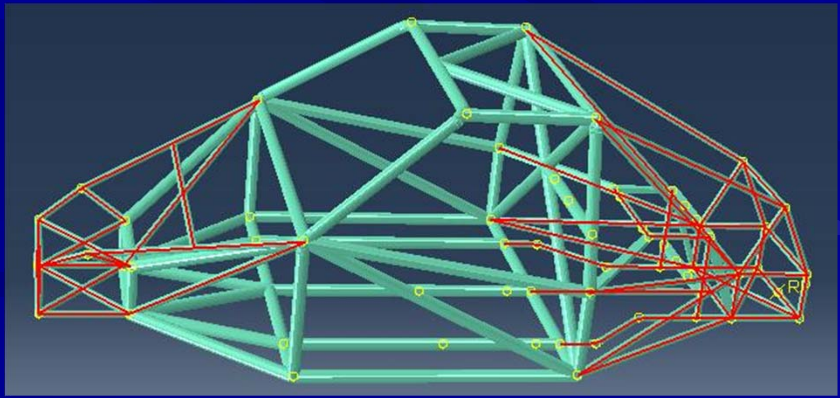


•**Chassis parameters**

- General dimensions:
  - -Length = 3750 mm   -High = 1030 mm
  - -Width = 1750 mm   -Weight = 139 Kg
  - -Wheelbase = 2800 mm
- Dimensions of tubes:



Cockpit: 50x2 mm



The rest: 30x1.5 mm

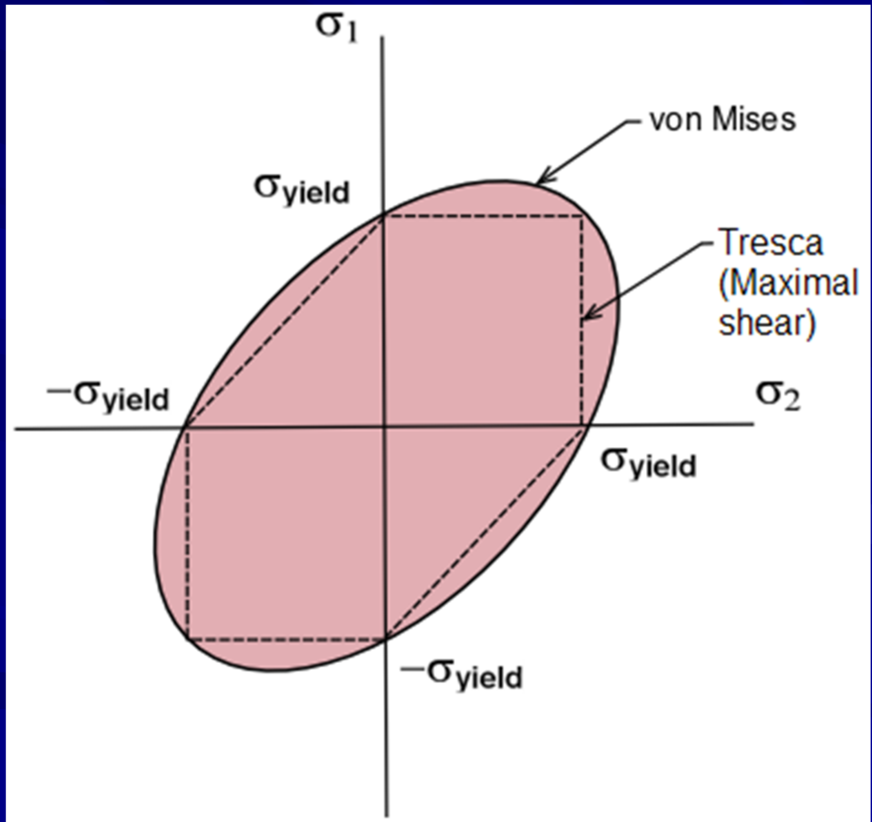
•Material

- Why steel?

-Steel properties: 317L (S 31703)

Density = 8027 Kg/m3
Creep limit = 336 MPa
Modulus of Elasticity = 200,000 MPa
Poisson ratio = 0.31

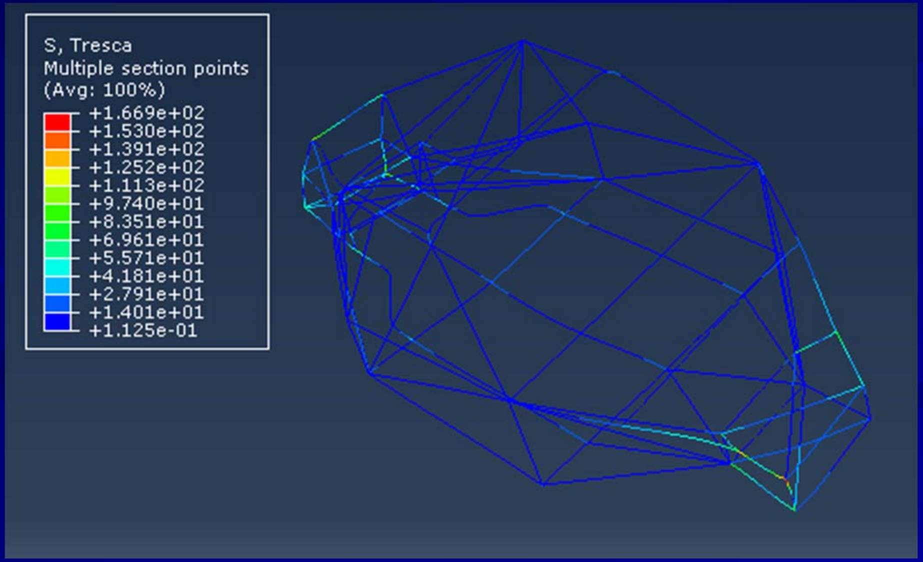
•**Choose the calculation theory**

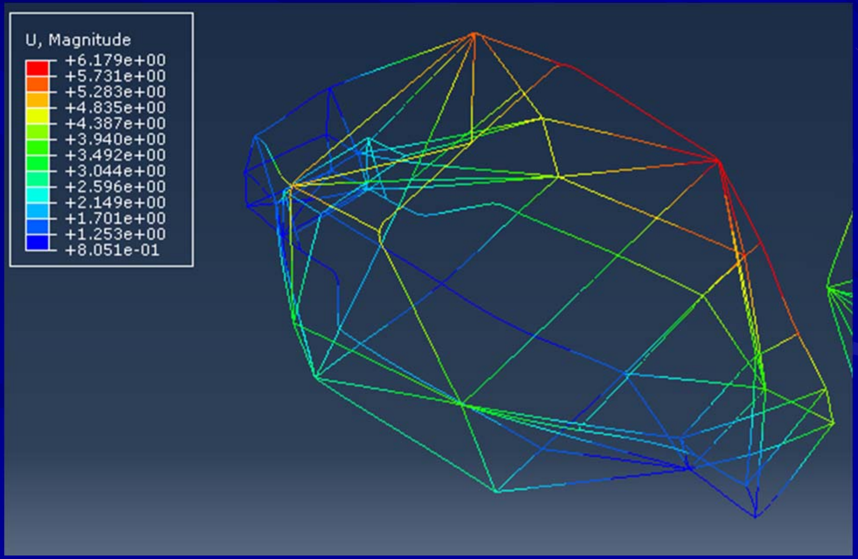


•Submit the chassis to the efforts

Three cases of analisys:

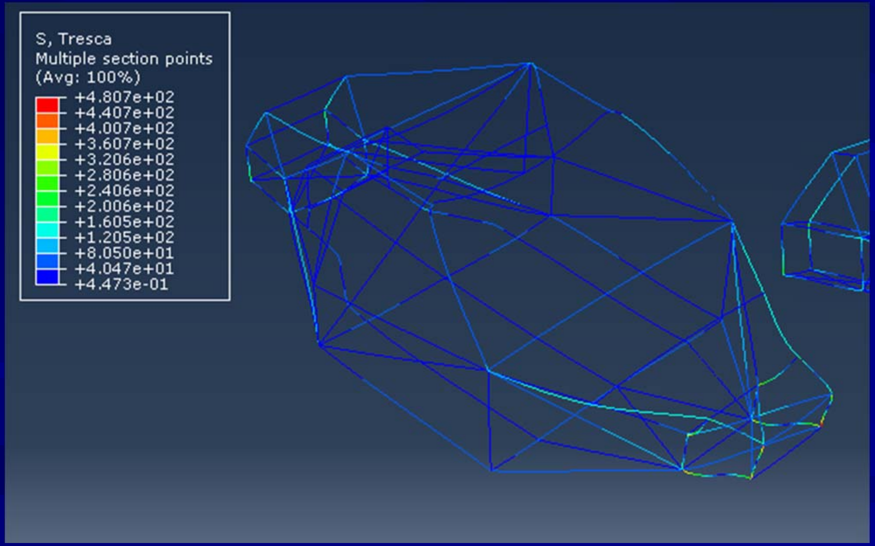
- Acceleration
- Braking
- Cornering (worse case scenario)

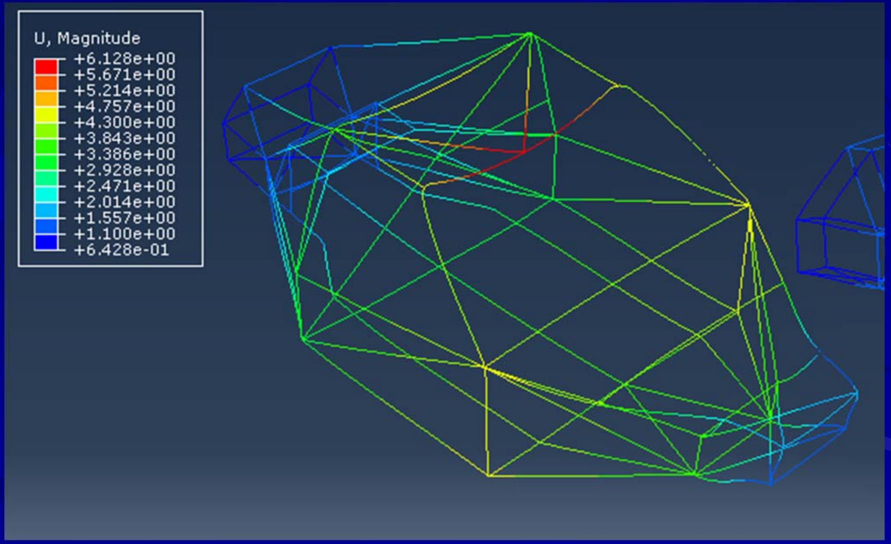




•**Submit the chassis to the efforts**

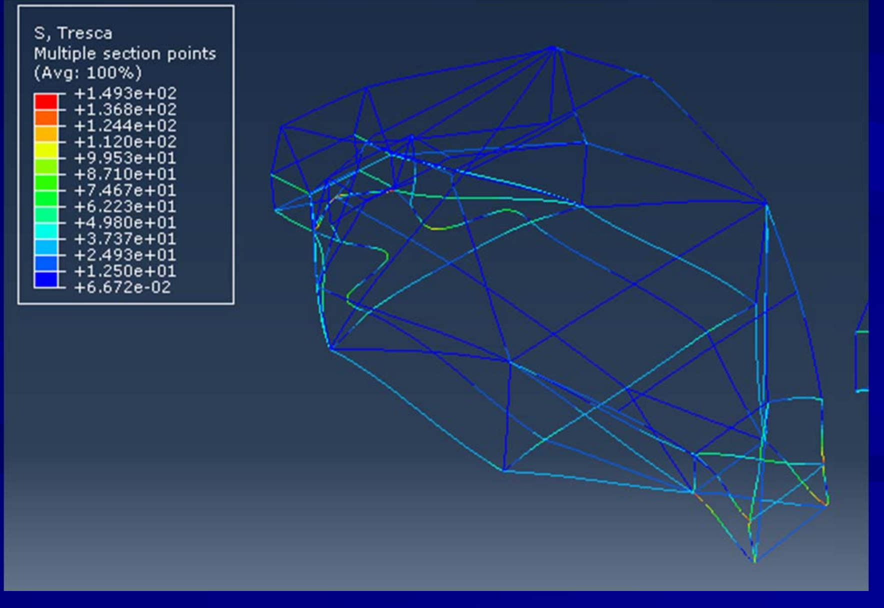
Vertical Crash: 8 times the weight of the car

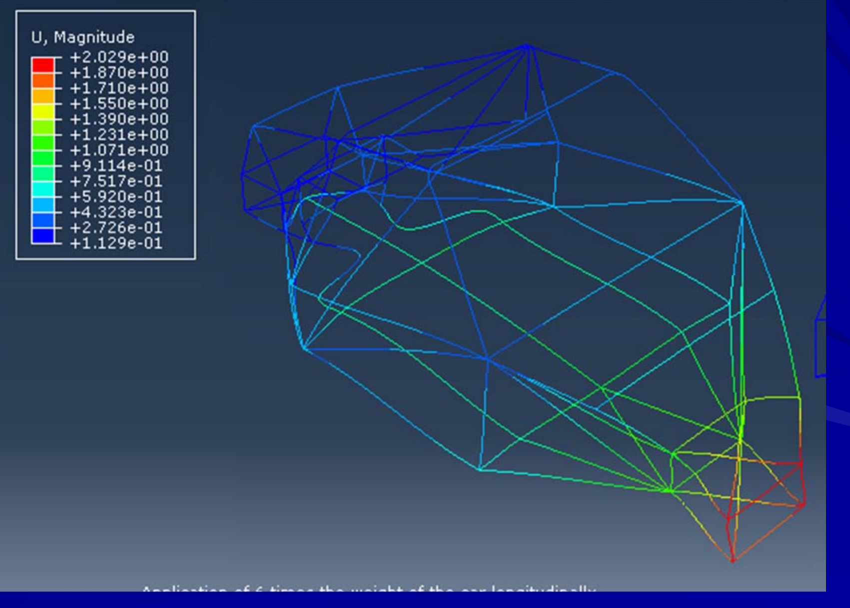




•**Submit the chassis to the efforts**

Longitudinal Crash: 6 times the weight of the car





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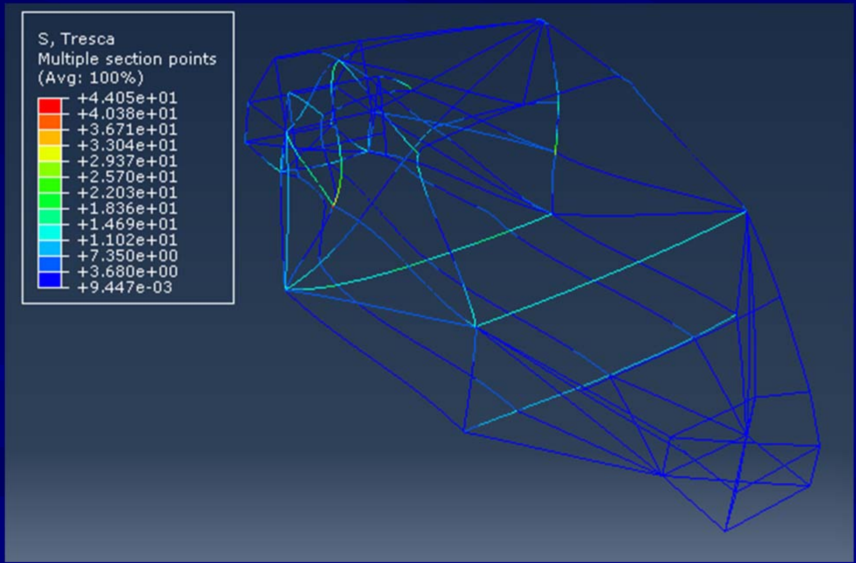
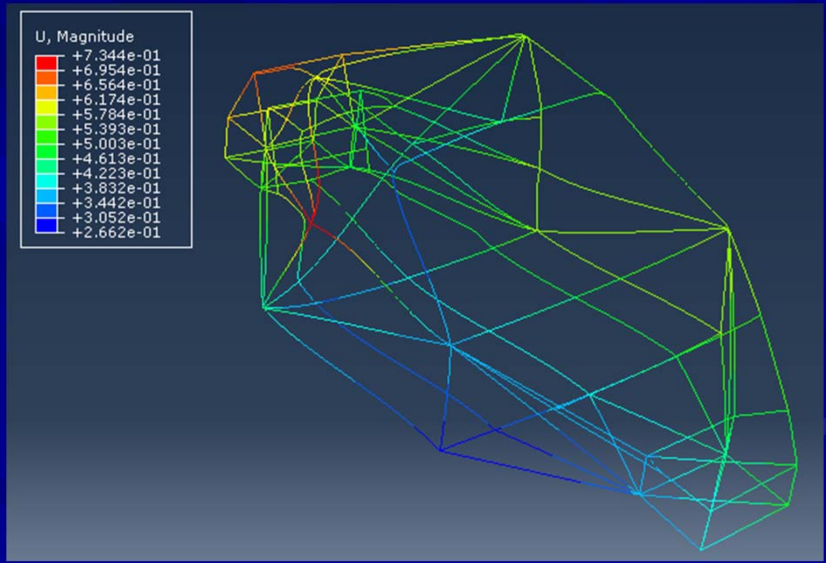
•Submit the chassis to the efforts

Lateral Crash: 2 times the weight of the car





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Conclusions

- The results are correct

- The objectives are achieved

- Removing some material, could be got a lighter chassis.

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